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PROJECT ADMINISTRATION DATA SHEET

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Project No. E-27-615 — DATE 2/25/82

Project Director: Dr. L. Howard Olsen — School/Lab Textile Engineering

Sponsor: NASA: Ames Research Center; Moffett Field, CA

Type Agreement: Grant No. NSG-2356, Supplement No. 4

Award Period: From 1/1/82 To ~~12/31/82~~ ~~2/28/83~~ ~~3/31/83~~ 4-30-87 (Performance) ~~2-28-86~~ ~~12/31/83~~ ~~2-29-84~~ ~~3-31-84~~ ~~6-31-85~~ ~~10-31-85~~ ~~11-30-85~~ 12-31-87 (Reports)

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Title: Development of Molded, Coated Fabric Joints

ADMINISTRATIVE DATA

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Defense Priority Rating: N/A — Security Classification: N/A

RESTRICTIONS

See Attached NASA Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with See NASA Supplement

COMMENTS:

Continuation of E-27-675

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SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 3/9/88

Project No. E-27-615 School/~~Lab~~ TE

Includes Subproject No.(s) N/A

Project Director(s) L. Howard Olson GTRC/~~GIT~~

Sponsor NASA

Title Development of Molded, Coated Fabric Joints ~~Proposal for Coating and Heat Forming of Fabric Specimens~~

Effective Completion Date: 12/31/87 (Performance) 12/31/87 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [X] Final Invoice or Copy of Last Invoice Serving as Final
- [ ] Release and Assignment
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E-27-615

FINAL REPORT ON NSG-2356

"Development of Molded, Coated Fabric Joints"

for NASA Ames Research Center

by

L. Howard Olson

School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

March, 1986

Guide to the Set-Up and Production of Tubular Woven Fabric

I. Introduction

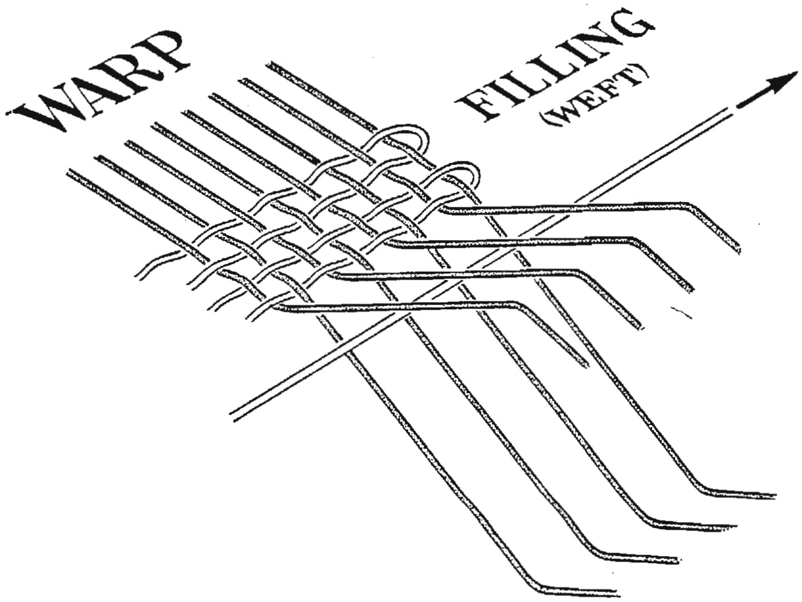
Manufacture of conformal, shaped elements for research on the NASA space suit has ensued from the acquisition of a Draper Model X-2, 29, narrow fabric inch loom. The conformal elements may be rolling convolute or toroidal convolute in design, but have a common mechanical benefit in formation from seamless, plyless tubular fabric.

The following material combines information on machine setup with a guide to production of the conformal element fabric. In the portion immediately following on machine setup are 1.) the comments on yarn handling, warping and quilling, and 2.) loom operational setup procedures. The production section covers fabric quality related adjustments to the operating loom, and means to change fabric design. The efforts of both sections are keyed to research levels of production of tubular fabric elements. Additional comments will discuss the setup and operations required to produce runs of the fabric beyond six to ten yard pieces, namely in several hundred yard runs. The reason for adding comment on long runs are as follows.

Observation of short-run efforts to date are that the setup/start-up time and costs consume the greater portion of allocable time and budget. In contrast to this, production time and costs are one-tenth and less of total involvement for work done to date. Off-quality goods also decrease with longer runs if a percentage basis of comparison is used. The research advantage found for the short run system is in versatility. As an aside to this, the short run system can produce a fabric from a single package or lot of fiber. When subtle changes in fabric weave tightness or fabric diameter are needed, either system normally achieves acceptable results. Gross changes of weave tightness (density) or fabric diameter usually require sufficient change to the machine components and yarn delivery system that tearing down the old setup and starting from scratch is necessary. The planned short run fits this requirement best. A gross change is one which leads to the need to form a new warp beam or replace the reed/drop wires/harnesses. As a final comment, the short run system is very dependent upon dedicated technician support. The timeliness of short run completion is a function of consistent machine operation and technician expertise in resetting components to accommodate changes.

II. Warp Preparation

The warp in weaving is the lengthwise set of yarns. Those yarns are interlaced with the filling or weft set of yarns according to some design in order to make a fabric. Figure 1 illustrates the interlacing of warp and filling yarns. Warp preparation is the process of coating the warp yarns with a protective layer or size, and then winding the yarn under uniform tension onto a warp beam.

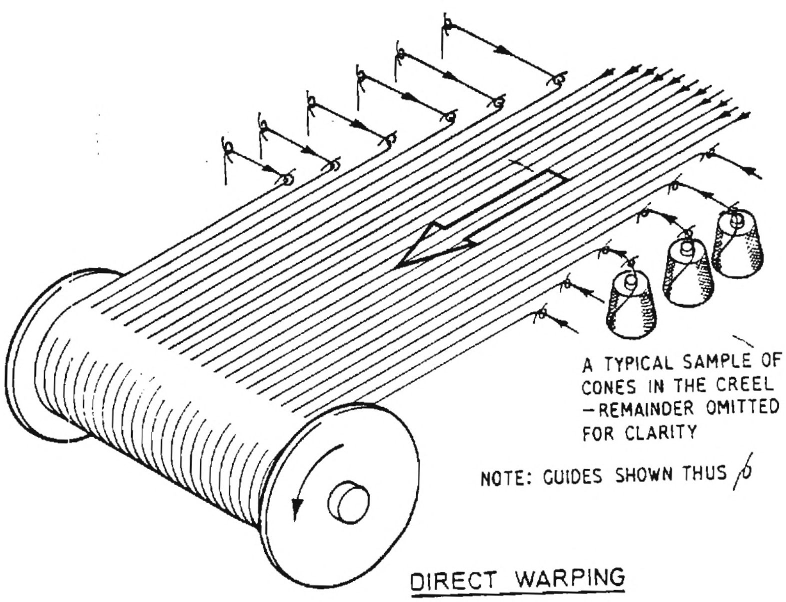


Warp and filling yarns are characterized by fiber type fiber crimp, yarn manufacture method (spun yarn vs. continuous filament yarn), yarn twist, and if plied, the ply construction.

Figure 1. Warp and Filling Yarn

The beaming operation is normally performed from multiple packages of yarn. The hundred or several hundred packages in the warp yarn creel are passed through tensioning devices that have been preset to a consistent tension level. The parallel, flat sheet of yarns are wound onto a beam. Figure 2 illustrates the warp beaming operation. Of the number of yarns in the creel are by some integral divisor fewer than needed for weaving, then the beam thus formed is referred to as a section beam. Either from the initial creel of yarn packages or from a combination of section beams, a warp beam is formed. The reason for winding to a section beam include: 1.) having insufficient floor space or funds for a full creel, 2.) having large supply packages of yarn which need to be concentrated by being consumed in one or a few warp beams to avoid crossing fiber manufacturer's merge numbers, and 3.) to satisfy width or density limitations at the creel or at the sizing operation.

The short run beaming operation is based upon the old principle of the silk reel. Figure 3 is a schematic diagram of a silk reel. A silk-type reel was constructed at Georgia Tech to perform warp beaming from limited supplies of yarn. The structure is basically a large wheel, twelve yards in circumference by one yard wide. Design of the reel is based upon stiff spokes held in position by tensile cables. The yarn to spoke bar contact points at the periphery are protected by Teflon tape. The feed of warp yarn to the reel is through a traversing guide. The guide lays the warp yarn



Constant tension end to end is a goal in beaming. The creel is initially set-up by measuring and adjusting the tension at every feed to a constant value, for example, ten percent of breaking load.

Figure 2. Warping

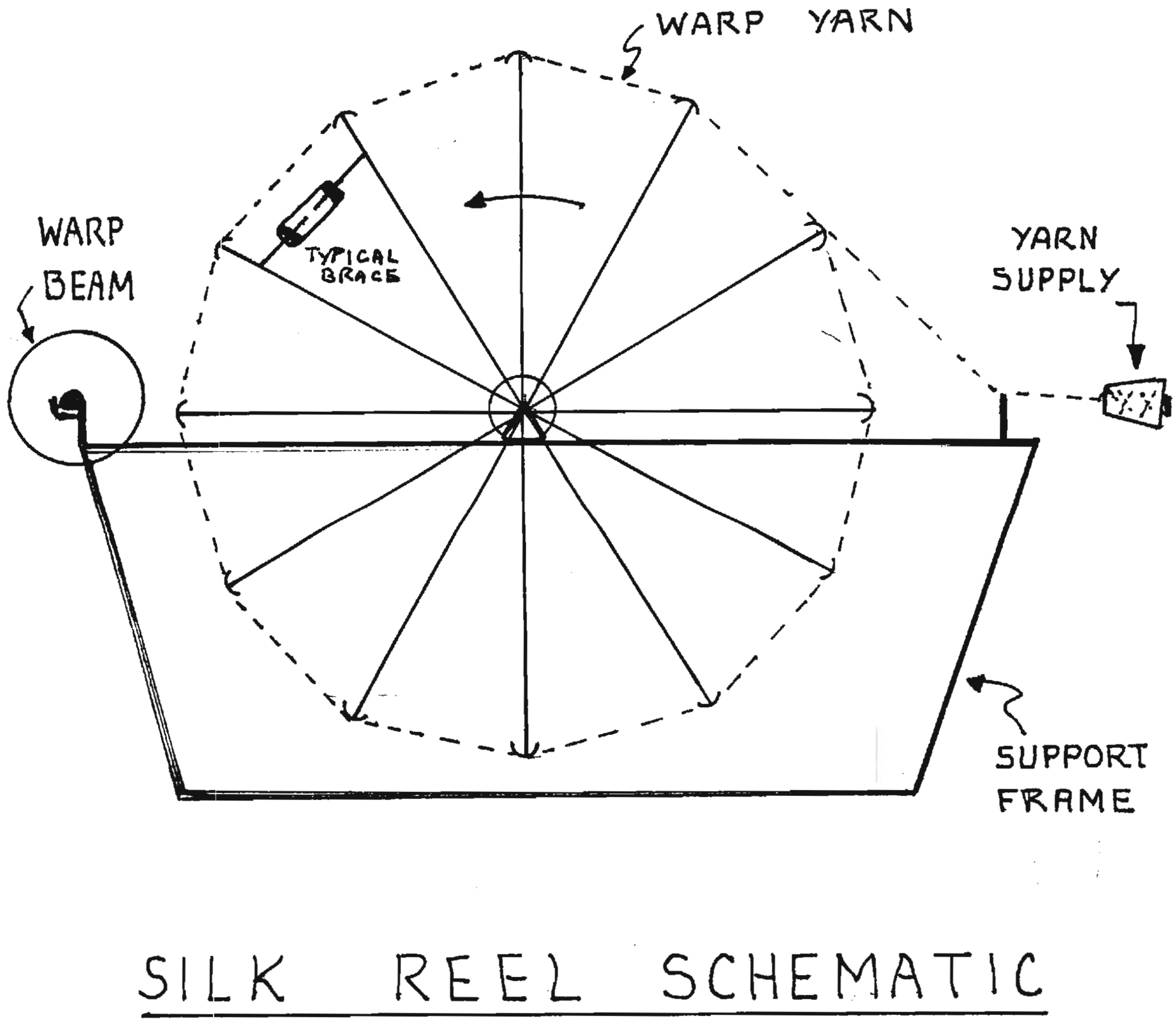


Figure 3. Silk Reel

onto the reel surface at the correct lateral spacing for later direct transfer to the warp beam. The guide is driven from the main reel by a gear train to a lead screw. The guide follows the lead screw by a split nut latch which can attach to or release from the lead screw. Change gears of the common spur gear variety are used to vary the lateral increment per turn of the reel, i.e. to vary the warp ends per inch.

For a flat woven fabric of N total ends in the warp, a relationship which may be useful in setting the beam flange width is:

$W = N \times D/2040$,

where the terms used are:

W, width between warp beam flanges in inches
N, total number of warp ends in the warp and
D, total denier of one warp end.

The length of yarn that can be placed on a warp beam is a function of the beam core diameter, d_o, and the beam flange outer diameter, d_f. The total length relationship is:

$L = 1020\ (d_f^2 - d_o^2)/D$,

where the terms used are:

L, total warp yarn length on the beam
d_o, core diameter
d_f, flange diameter
and
D, total denier of one warp yarn or end

These are useful relations for first time setup of a production beaming operation.

Tension control on the silk reel is by means of a relatively simple disk tensioning device. Because of several factors, including that the yarn flows from a single package, the yarn typically involved is a uniform, smooth synthetic continuous filament, and the yarn has very uniform surface finish (yarn lubricant) application over the length of a reel run, a simple tensioning device performs well in terms of laying the yarn onto the reel at a consistent tension. Beam tension is generated later and only consistency is needed at this point.

Transfer to the warp beam involves taping a three foot section of the warp while it is on the reel. Adhesive tape is pressed onto the upper and lower warp yarn surfaces. Then the tape and yarn sandwich is cut across at one foot along the taped section. The two foot taped section is laid out onto the warp beam first. When the warp is nearly consumed at the loom, tension in each warp yarn is at a maximum. The longer taped section on the core of the warp beam reduces the chance of a random yarn pullout. Losing a warp yarn or even the warp yarn tension renders the remainder of the fabric as second quality. Additionally, a loose yarn can cause the shuttle to be ejected from the warp shed with consequent warp damage and risk to personal safety. Thus, care at warp beam formation is a key to success with the short run weaving process.

The silk reel has a brake so that winding from the reel onto the warp beam can be done under tension. Beaming tension is 5% to 10% of beam tenacity, i.e. total tensile strength. A 0.003 inch nominal thickness paper is precut to beam width and fed to the beam as a continuous sheet with the warp yarn. The paper separates layers of warp yarn. If a yarn slips from its layer to a lower layer during beaming, a tight end will appear in the woven fabric. This can be a major defect with respect to NASA requirements. Similarly, if a warp yarn were to slip to a lower layer during weaving, a loose end will appear in the fabric. Again, this a a major defect generating seconds quality woven goods.

III. Filling Yarn Winding (Quilling)

Filling yarn may come from one or a few yarn packages, twenty or less, in a normal mill operation. The short run system uses the same package of yarn for filling winding as was used for warp beam preparation. A Unifil winder which has been used extensively for automatic on-loom filling winding over the past years of fly shuttle weaving is being used at Georgia Tech to do the winding. There is no preference for a particular quill winder (quiller), such as the Unifil. But there is a stringent need for attention to burrs and sharp edges which may fray the filling yarn.

The textile industry is rapidly and drastically changing its method of filling insertion in the weaving process. Shuttleless weaving obviates the need for quillers and means that quill winders will become increasingly rare. The needs of NASA are covered for some time into the future by specialty weaving houses and the textile schools retaining traditional equipment.

The quill or filling bobbin which receives the filling yarn is selected for size according to the shuttle size in which it will be used. Figure 4 is of a quill showing its position in the shuttle. The NASA loom at Georgia Tech, for example, uses an eight inch standard quill with a number 7-butt, set up for automatic changeover in a Draper shuttle. Unifil start-up clips are found on the head end for automatic transfer of quills at the winder. The quill itself will become a rarer and therefore more costly, specialty item from textile mill suppliers.

The short run system of warp and filling preparation has all of the fabric yarn coming from one package of yarn and from one rather small region of the yarn package. This gives the best of yarn consistency in the fabric samples used, for example, for coating adhesion comparison tests.

For production runs of fabric which are not involved in comparative research testing, the concern over yarn consistency is unnecessary. Yarns from a single shipment or lot are usually consistent from package to package well within acceptable variability of surfaces finish, diameter and polymer characteristics. Yarn variability from lot to lot within a fixed merge number can be tested for changes in properties. The odds are good that maintaining a merge number is adequate to maintain processing characteristics in a consistent fashion, which generally infers that performance properties will be consistent as well.

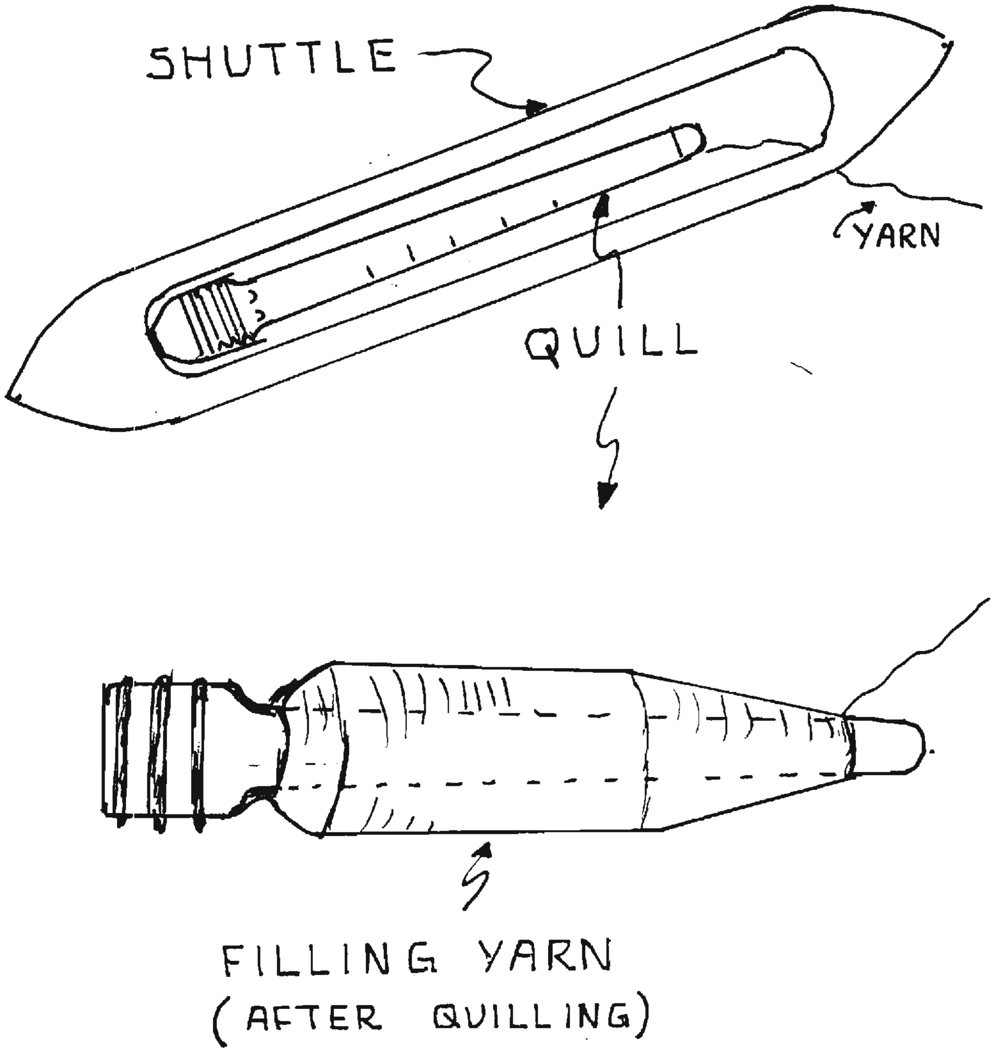


Figure 4. Quill

IV. Fiber Quality Assurance

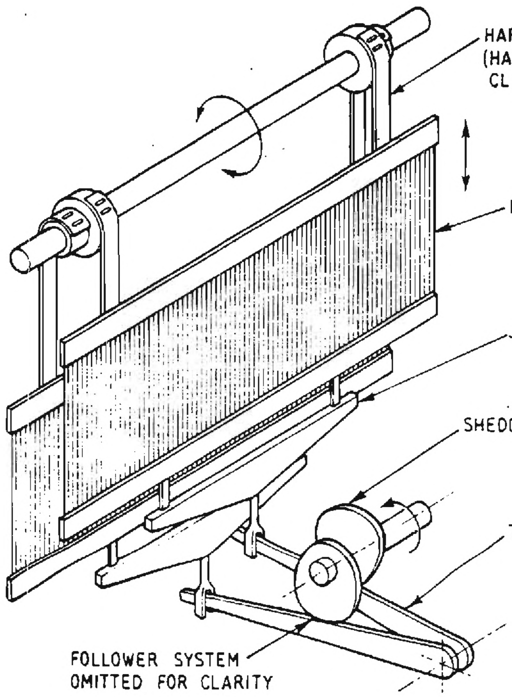
Quality assurance tests on warp and filling yarns to provide an incoming raw materials check should include fiber finish level, single end tensile strength/elongation, and visual confirmation by label of the fiber type and total denier. The strength/elongation tests when compared with historical records give information beyond the obvious endpoint data. Polyester, for example, has characteristic sets of properties that clearly differ from nylon or polypropylene in the commercial grades of each fiber. Also, the consistency versus scatter of individual test data points is a potential data resource, provided that good test methods are adopted. The commercial test standards for fibers are given under ASTM standards and under Federal Standard 191 on textile test methods. The American Association of Textile Chemists and Colorists has published standard test methods which include determination of fiber finish level and fiber identification. Refer to Appendix E for specific information on these standards. Checks on fiber finish level have been shown in recent research to be amenable to use of near infrared spectrum analysis. Technicon, Inc. in Tarrytown, NY can provide a turnkey analysis system and has done so for several (20-30) industrial fiber users.

Normally, the denier of incoming untextured continuous filament yarn is not tested in textile production environments. Denier is a measure of linear density defined as the mass in grams of a nine kilometer skein of yarn or

The loom at Georgia Tech that has been used for weaving tubular fabrics is the aforementioned Draper X-2. Appendix A is devoted to parts identification on the X-2 loom. Appendix B describes loom gauges available from Draper Corporation for setting the X-2 loom. Appendix C describes setting the link-type parallel used for picking (shuttle projection). Appendix D describes shuttle box alignment. Appendix E describes reed alignment. Each of these appendices is taken directly from Draper literature. This literature has not been published for twenty years and is now unavailable. Therefore, the appendices are being used as a resource for materials not otherwise available.

Setting the loom is not required normally at each start-up. Occasionally settings do slip by nature of the design of the loom. A trained technician can affect repairs at a time savings ratio that approaches one or two orders of magnitude. Nevertheless, when necessary, any technician may undertake loom setting for operation, following the pertinent guides.

Not covered in the appendices is setting harness motion cams which control the weave design or pattern. Figure 5 shows the relative position of the cams to the harness assemblies. The cams lock together as a set. They are mounted on an auxiliary cam shaft which rotates at half the angular speed of the main cam shaft. The X-2 intends in this instance to weave a tubular or double fabric. As the loom makes two cycles the main cam shaft rotates once which



The number of cams and harnesses required in a loom is at least equal to the length of the pattern repeat.

Figure 5. Harness Motion Cams

is adequate for a single layer fabric and associated cams. The auxiliary cam shaft has been geared for the four cycle repeat of a double fabric at half the angular speed of the main cam shaft. The difference between the cam arrangement for tubular and double width fabrics is only in the stacking order of the cams. A set of cams will have two (A type) that are designed for lowering the harnesses over three quarters of their cycle and two (B type) that lower the harnesses for just one quarter of their cycle. If the cams are set out in an AABB fashion versus ABAB the yarns interlacing upper and lower portions of the fabric will be changed. In both instances, the cams are distributed at ninety degree increments around the shaft.

Using a notation that X represents a lifted harness and O represents a lowered harness, the designation is that of a single fabric plain weave. Each horizontal row represents a filling pick. Each vertical column represents a warp end controlled by its own individual harness. The X also infers that the warp end is above or on top of the filling pick. With this notation in hand, the double width fabric appears as:

OXOO
XOOO
XXOX
XXXO

while the tubular fabric is represented by:

OXOO
XXOX
XOOO
XXXO

In other words the second and third picks only are interchanged to change the fabric design. Each pick column represents the activity of one cam over one fabric design repeat. Obviously, the difference between the two is that the second cam from the left is rotated forward 180° and the fourth cam is rotated 90° forward. Other combinations will weave, but some are a double thickness single fabric tied together by one end in four crossing from top to bottom fabric layers and returning.

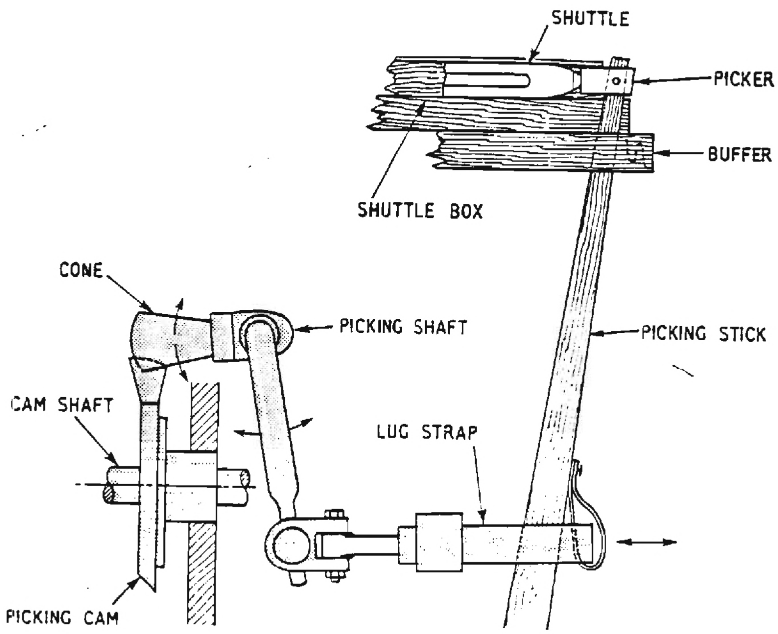
With this discussion of cam setup aside for the time being, a later section will cover alternative tubular fabric weave designs that can be accomplished in six and eight harness repeats. A cam loom becomes increasingly sensitive to settings and wear as the number of harnesses is increased. It is recommended that six and eight harness patterns be developed with a dobby head for pattern control rather than a cam system.

As confirmation that shuttle picking, shuttle flight, and shuttle boxing are set properly and before any long fabric run, the Georgia Tech loom is "rocked in" by operating the loom for an hour or more without warp yarn or filling. Figure 6 illustrates essential parts of a picking system. The warp and filling stop motions are bypassed for this. The crucial point of this test is that if the shuttle flight is not true and flat the shuttle will be ejected from the loom. Warp yarn can correct the flight path of the shuttle allowing operation of a mis-set loom. Contact with the warp yarn by the shuttle more than is necessary will fray the yarn. Shuttle burrs are corrected by sanding down with grades of emery paper, ending with a crocus cloth burnishing. A shuttle wax is then applied. This may seem excessive, but the warp yarn near either end will be brushed by the shuttle as many as one hundred times before leaving the shedding zone. Set points include position of the four bar picking linkage known as the link parallel, check of box to reed and to opposite box flatness by a tool steel gauge, and shuttle capture by the boxes.

Most of the expendible parts, such as check straps and frictional lining in the boxes, have a life cycle of six to twelve months even with twenty-four hour continuous operation. Thus, the loom at Georgia Tech can be expected to have many years as the life cycle of expendable components.

VI. Warp Draw-in

The warp draw-in is the last operation prior to



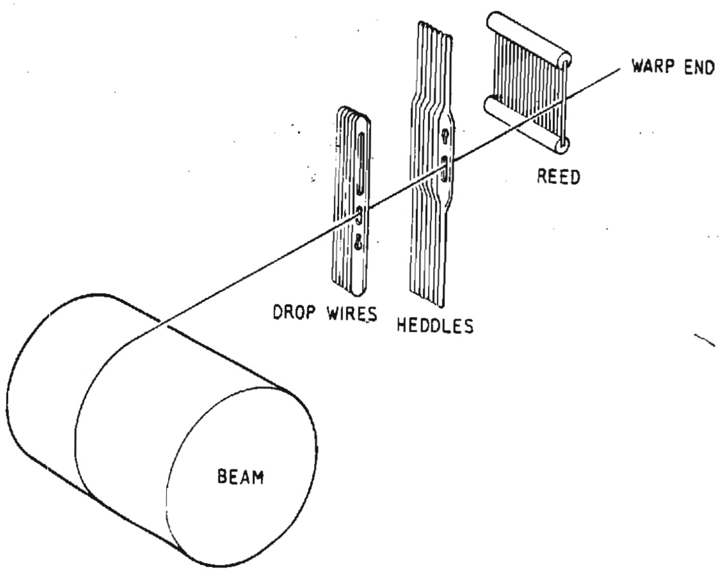
There are slight variations on this picking system among various traditional looms. New loom technology primarily affects this system, and predominates in industry. Tubular fabrics cannot be constructed on looms using the new technology.

Figure 6. Picking System

weaving. The warp yarns or ends are literally drawn one end at a time through the drop wires, heddles, and reed dents, as Figure 7 illustrates. In a production environment the draw-in is performed on automated machines set up for the particular draw-in pattern, yarn size, and loom beam width/style. For the 29 inch loom at Georgia Tech, there was no automated device on hand, nor was a machine servicing looms of this width locatable in this country. There has in fact been no sale of a 29 inch X-2 loom in this country over the past 35 years, which precedes the development of automated draw-in machines. As a consequence, the warps on the narrow loom are hand drawn. A reed hook is the device used for manual draw-in.

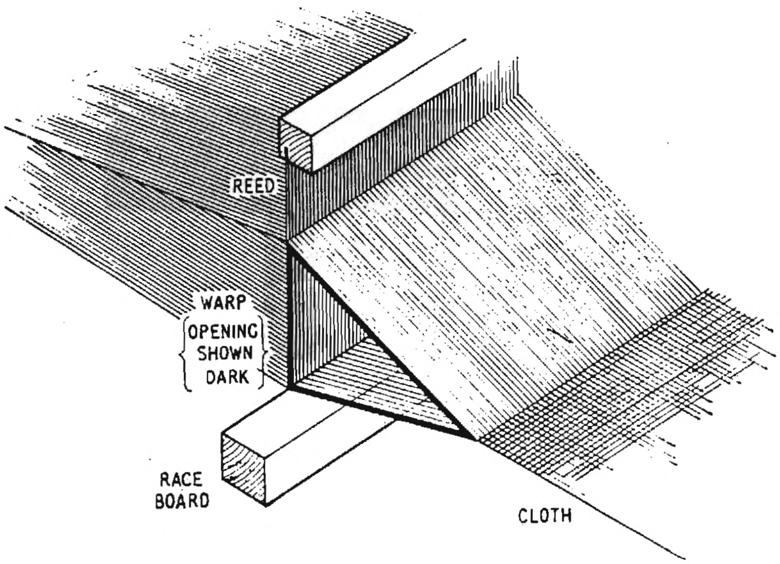
The draw-in pattern is of concern from two viewpoints. Firstly, the draw or draw-in pattern can affect the relative abrasion between warp yarns during shedding. The shed is illustrated clearly in Figure 8. The key is to avoid having harnesses which cross most frequently as adjacent pairs. Secondly, the draw-in affects time to make repairs to broken warp yarns (ends down) by having a fixed order and grouping of yarns. Some of the candidate NASA fabrics have eighty warp yarns per inch width. Finding the one which is down is assisted by noting its pattern group and then breaking that group down.

It so happens that the draw-in pattern for the four harness tubular fabric is adequately served by a simple one through four direct draw. This is illustrated in the following.



Defining the draw-in components: a.) the drop wires are very thin, copper plated sheet metal parts which make warp stop motion system electrical connections if allowed to fall; b.) the heddles are constructed similarly to drop wires and lift the warp yarns; c.) the reed separates the warp yarn in a uniform way to control the lateral yarn spacing.

Figure 7. Warp Draw-In



The shed is formed and closed at each pick across the loom. This may occur at rates up to ten cycles per second. There is abrasion as the warp yarns cross.

Figure 8. Shed Opening

following.

```
     Straight Draw        OOOX
                          OOXO
                          OXOO
                          XOOO
```

An option was to offset the middle pair.

```
     Offset Draw          OOOX
                          OXOO
                          OOXO
                          XOOO
```

The draw-in pattern has a different meaning than that given for the weave design. X represents a draw-in point and the O, a miss point. The four vertical columns represent a repeating group of four adjacent warp yarns. The four horizontal rows represent four harnesses or four ranks of drop wires.

Normally, draw-in occurs off the loom in a frame set up for that purpose. The first step is to pull the warp through the drop wires and the harness/heddles, then to pull the warp through the reed. A typical warp for the narrower tubular fabrics provided to NASA has one thousand ends. The draw-in required twenty hours for an unexperienced technician; and there were draw-in errors to be corrected on the loom. An individual draw-in error can make necessary redrawing half the yarns, another ten hours of work. There are a few textile mills with draw-in frames and personnel. These mills offer clearly the preferred alternative means of performing this operation.

VII. Harness Setting

The drop wires, harnesses, and reed are placed in the loom as a set. While drop wires and reed are located rigidly by loom components, the harnesses float. The harness action is of the positive pull down type. Cams act on treadles to drop the harnesses to their lowered position. An overhead clock-type spring (clock top) returns the harnesses to their raised position. The tension in the lifting spring is on the order of fifty pounds and will be varied according to loom speed and loom width in general production environments to assure that the spring return rate matches the cam fall away, i.e. the cam follower will not bounce.

The shed or opening formed in the warp yarns by lifting some harnesses and lowering others must be uniform and parallel to the loom raceway. The shed setup is illustrated in Figure 9. The height above the raceway of warp yarns should by 5/64 inch. This is set by a turnbuckle adjuster on the harness take-down yoke (jack stick). Treadle position and turnbuckle position on the treadle affect the displacement of the harnesses. A uniform upper shed is created by adjusting the treadle displacement. At full opening the shuttle will just clear the warp yarns. Warp yarns displaced into the shed can deflect the shuttle out of the loom during weaving causing a warp break out. Thus, the attention noted here to harness setting.

VIII. Loom Start-Up

The warp yarns are tied at draw-in in lots of two inches of reed spread on the face side of the reed. To

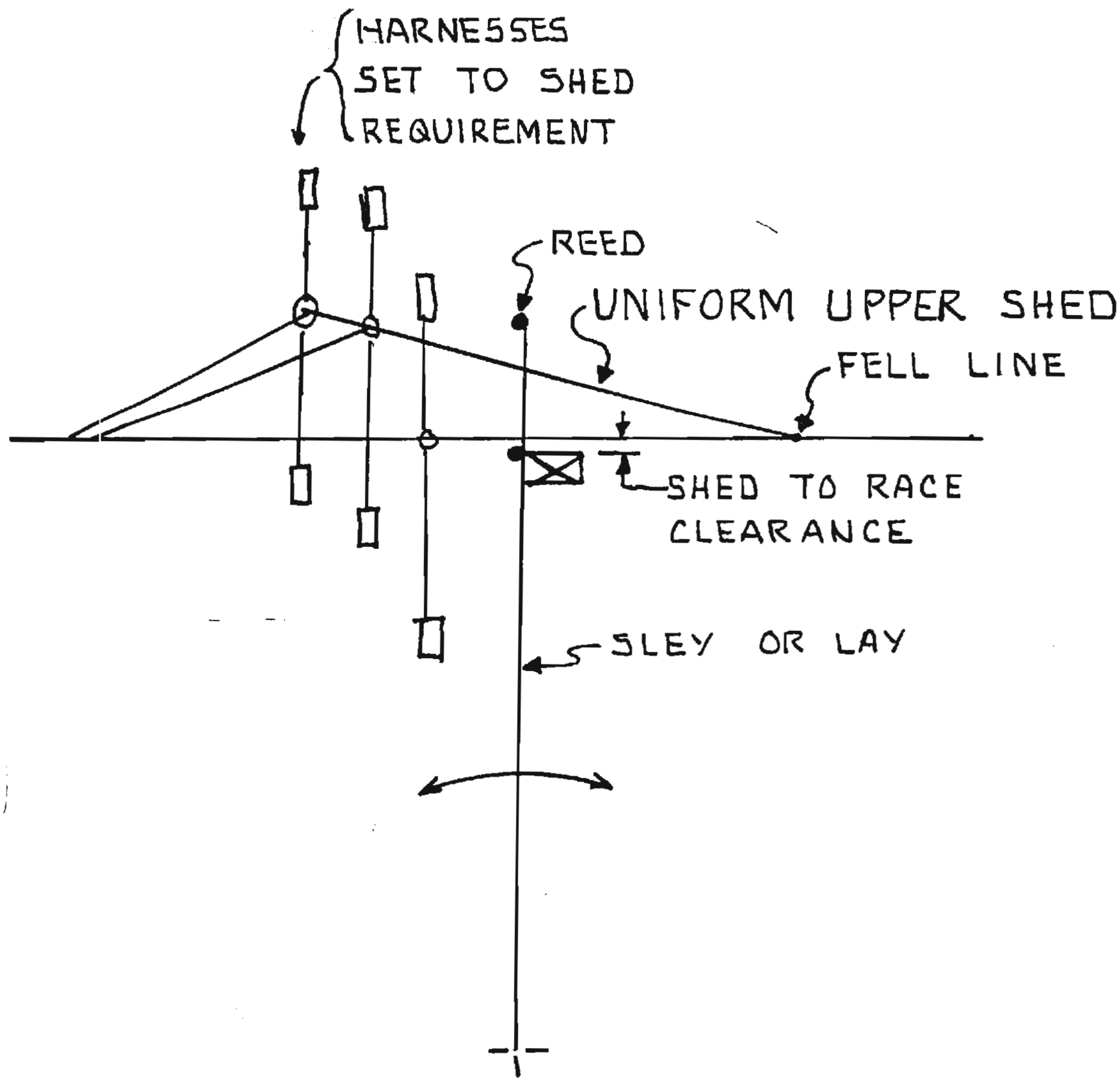
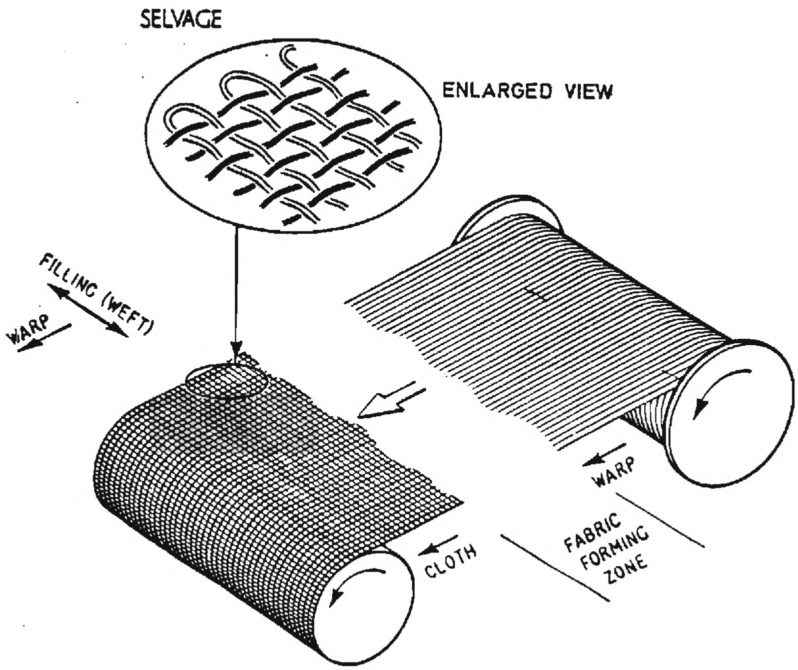


Figure 9. Shed Formation

assure uniform starting warp tension, each tied lot is untied and brushed with a course bristle brush. The effort is directed to placing uniform frictional drag on each end after setting the ends out in parallel order. A piece of woven fabric is stripped back to form strands to tie to the warp end lots being prepared by brushing. This fabric is delivered over and around the feed roll down to the cloth roll. Feed to the cloth roll and warp let-out are depicted in Figure 1Ø.

Several smooth wraps around the cloth roll assure that uniform take-up tension will be imparted to the fabric. The warp beam tension is provided by frictional drag. A pawl arm and ratchet for removing slack are found on the lower left front of the loom, driving the take-up roll and cloth roll. This is part of a clutch arrangement which allows the drive system to advance the feed roll as well. The feed roll is the positively driven part which controls the filling picks per inch in the fabric.

Fabric slip over the feed roll surface would disrupt the even spacing of filling picks. A nip or squeeze point is formed between the cloth roll and feed roll acting normal to the fabric surface. The friction developed at this point must exceed warp tension and any impulsive loads during weaving. A cloth roll spring, gears, and rack deliver this pressure. There is no gauge for this tension, but experience and inspecting for signs of cloth roll slip will allow for finding an acceptable level. Approximately fifty



The goals at start-up with respect to the cloth take-up roll and warp beam are to achieve a flat, parallel pay-out and take-up and to have uniform tension across the width of the fabric.

Figure 10. Warp Beam and Cloth Roll

foot-pounds of torque has been adequate on the eight inch diameter test fabrics.

The first picks are thrown across by hand. Four picks are necessary to develop one full interlacing of a tubular fabric. With eight to ten hand thrown picks starting the fabric, the fell line (beginning of fabric) becomes well defined and the shed opening stabilized for the first time. Immediately, any corrections to harness settings which appear necessary are made.

The filling yarn used at start-up is a cotton spun yarn whose cotton count (measure of inverse linear density) is equivalent to the Dacron polyester yarn denier being used or a little less in count number, i.e. larger in size. The soft and larger cotton filling yarn is used to take up those warp ends of low tension and yield under those ends of excessively high tension. The mechanism under which this occurs is crimp adjustment at each warp yarn interlacing. For reference, the cotton count of a yarn can be found from the formula:

$$\text{Cotton Count} = 5315/\text{Denier}$$

Approximately two feet of fabric has been woven with cotton before going over to the appropriate filling yarn in past test runs. Once another two feet of fabric has been generated, the fabric is inspected from under the loom for defects such as mis-draws and ends down (broken). All the time that start-up fabric is being generated, the fabric tension is held sufficiently high to avoid loose ends within the shed by means of the slack arm pawl. The warp beam settles into the higher value of tension used on the loom such that constant flow occurs.

Rather than risk damage to the filling yarn by automatic quill change the battery and change unit were disabled. A second reason for not using automatic change is that better fabric integrity can be obtained in hand changes. Test fabrics were made by tying the filling tails when quills were changed. Excess was trimmed such that the tails tucked into the fabric rather than protruded where interference with subsequent coating might occur. A quill provides about eight inches of fabric. Two yards of filling yarn are consumed in 0.075 inch of an elbow joint fabric.

The quills were wound less than full to avoid chafing on the winder or shuttle. Technicians were requested to wash their hands after any machine adjustment since a smudge on a quill can persist in the fabric over the full span of that quill's usage. Consequential to beaming unsized yarn is a tendency for warp yarns to cross behind the drop wires. At each quill change the warp yarn approaching the drop wires must be inspected and brushed parallel as the lead in yarn was during setup. Warp tension must be held constant to avoid start marks in the fabric. A skilled weaver can back up or advance a fabric by one pick's width and recognize when this needs to be done. The technician operating the loom should watch shedding closely for a dropped or slack end. Ear protection is required during weaving.

IX. Loom Operation

The fabric run is probably the simplest and least time consuming phase of operations. Fabric weaving is a very dynamic process in terms of having a variety of motions, a flying object (the shuttle), noise from shuttle projection object and a delicate filament yarn moving into a controlled pattern of interlacings. The weaver is in fact a careful observer within this environment. Anomolies in the moving yarn shed and changes in sound are keys to preventing problems. The next paragraph describes the functions occurring during loom operation.

The principle motions of weaving are shedding, picking, and beating up. Secondary motions are warp let-off and cloth take-up. Figures 11, 12, and 13 illustrate the principle motions respectively. Figure 14 adds a view of let-off and take-up. Shedding, performed by the harnesses, controls the weave design. Picking inserts the filling yarn into the shed opening formed by the harnesses. The beat-up by the reed presses the filling yarn into the fell of the cloth, a fixed position in space defining the beginning of the fabric. Cloth take-up advances the fell line in fixed increments. This establishes the number of filling picks per inch in the fabric. The reed fixes the spatial relationships between warp ends, establishing the number of warp ends per inch. Warp let-off serves generally as a system for maintaining constant tension. A few let-off systems are referred to as constant let-off or constant rate

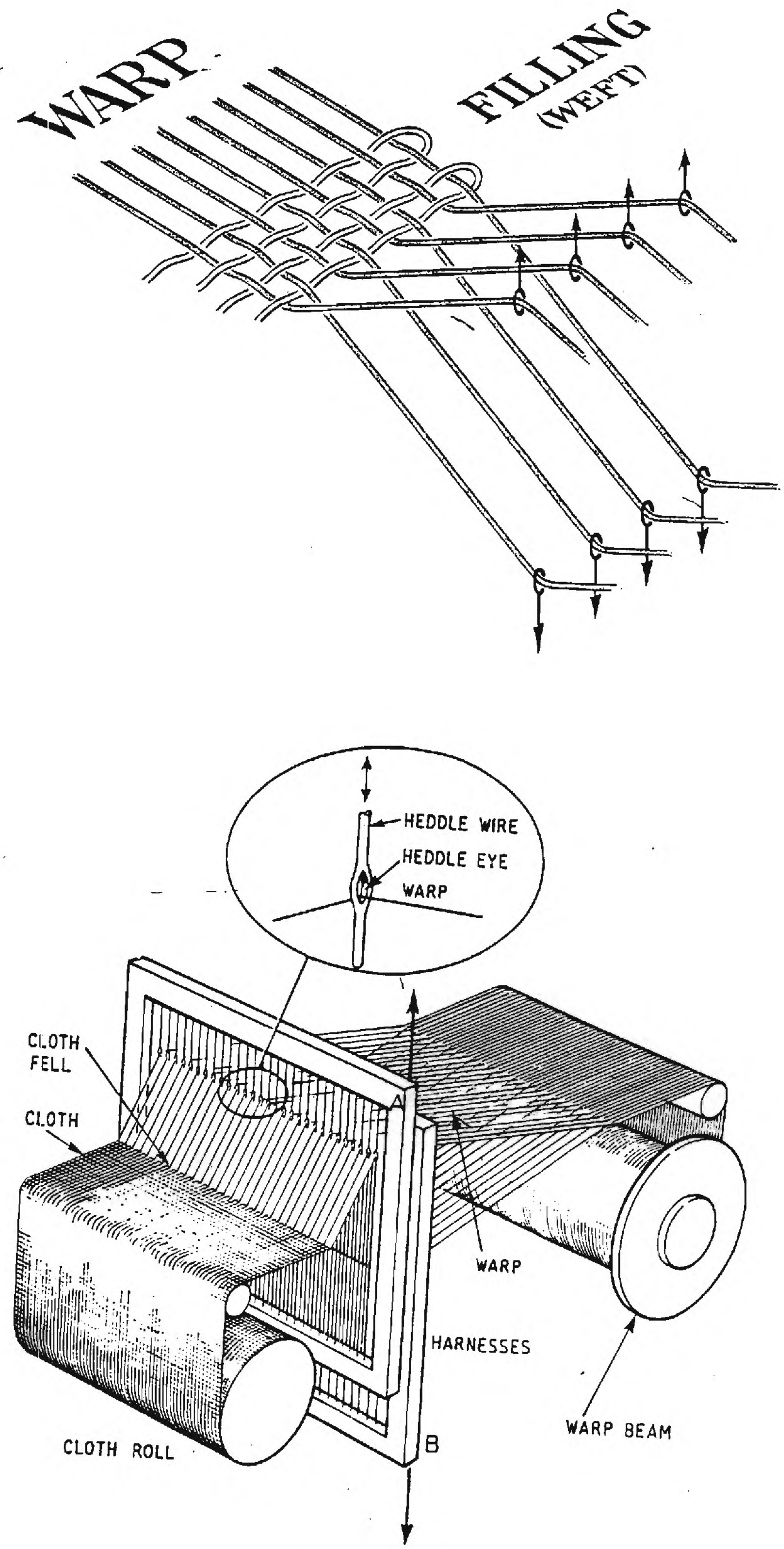
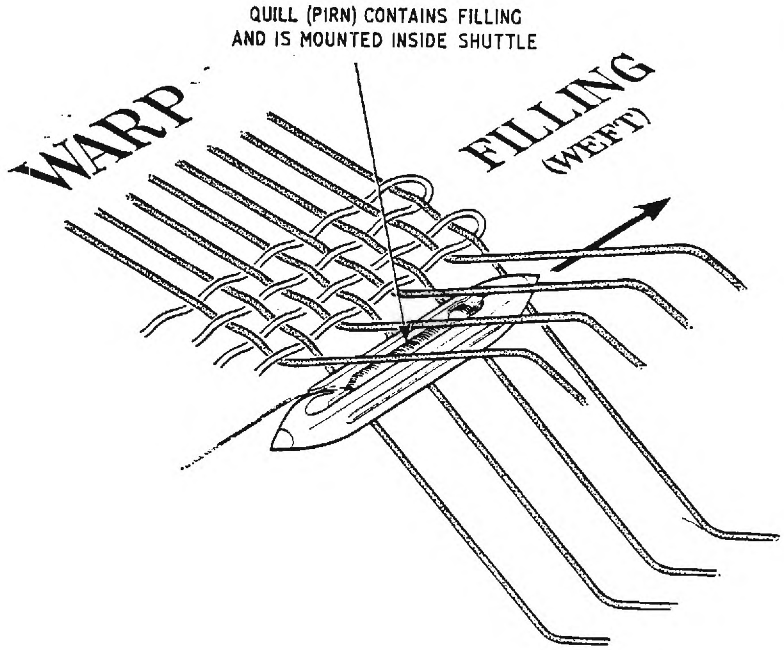


Figure 11. Shedding: Schematic and Pictoral Diagrams



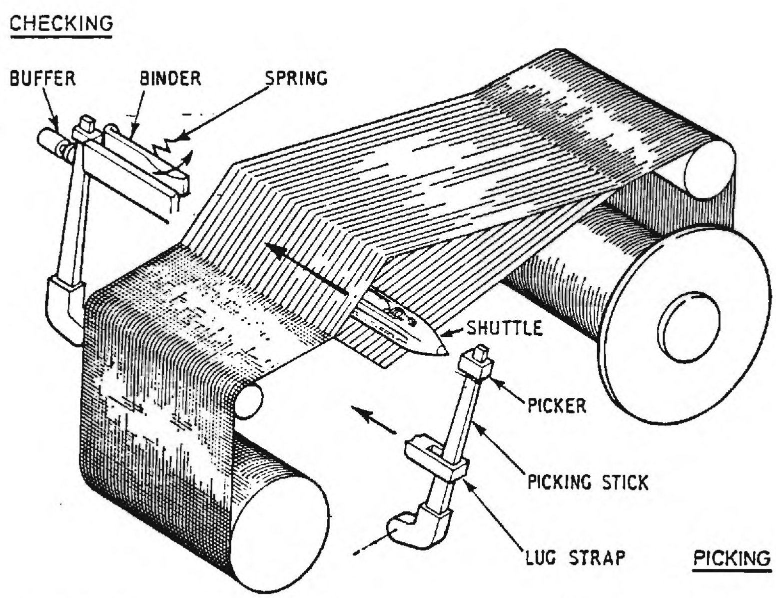


Figure 12. Picking: Schematic and Pictoral Diagrams

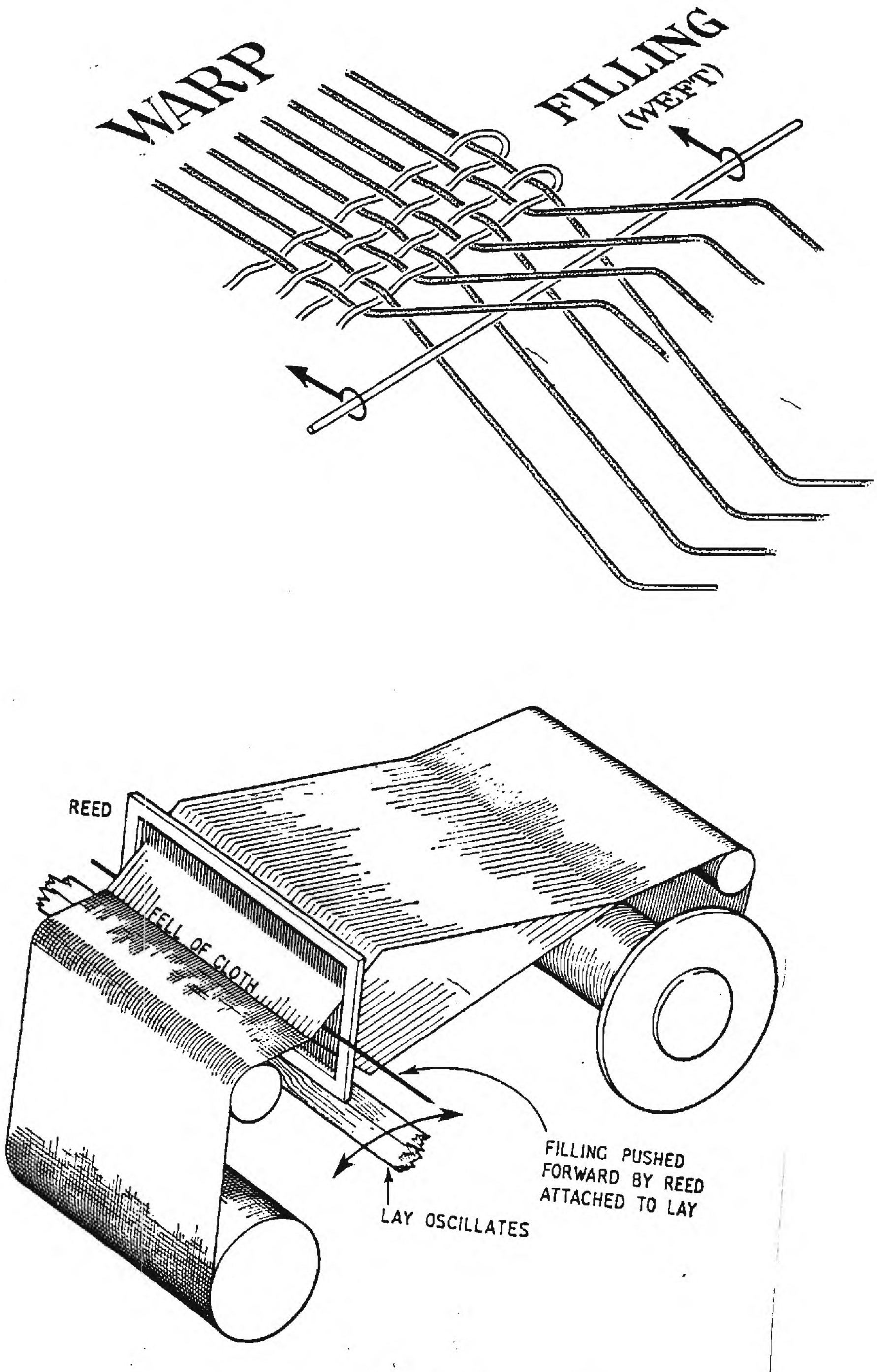
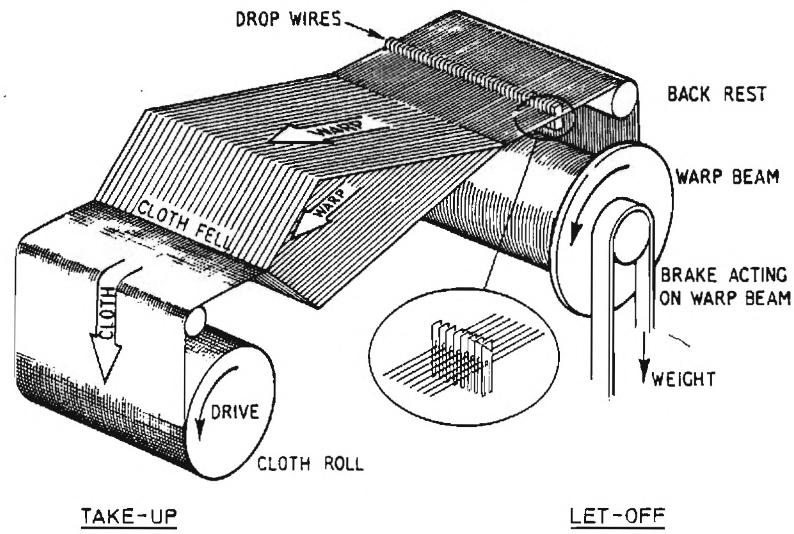


Figure 13. Beat-Up: Schematic and Pictoral Diagrams



Control of the fabric feed rate takes place at the take-up roll or breast roll immediately above the cloth roll. The take-up roll has a granular etched metal surface. Alternatives are smooth or textured rubber covering, grit paper covering and spiked clothing with fine protruding needles. Uniform feed is essential to having uniform filling pick distribution.

Figure 14. Warp Let-Off and Fabric Take-Up

of feed systems. The assumptions in utilizing the constant rate of feed are that warp crimp can be accurately calculated or empirically determined and that excessive tensions can be overridden. Awarness of these functions is important to the task of monitoring loom performance by the weaver.

A typical patrol of the machine consists of first walking to the rear of the machine to clear free paper from layers released in the warp beam and brushing back crossed yarns from the drop wires. Next each end of the loom is inspected for proper shuttle boxing. Shuttle boxing is the process of braking the flight of the shuttle. The shuttle must strike the picker head, which is restrained by a check strap, with sufficient energy to fully reset the picker stick to the back of its throw. Referring back to Figure 6., a picker stick is the mechanical arm connected to the link parallel which throws the shuttle across the loom. No bounce back should occur when the shuttle flight is checked in normal operation.

Energy is taken from the shuttle by the box sides through friction. Adjustment of this is part of loom setup, and checking on this during operation is worthwhile.

In an eight hour per day production environment, listening to shuttle boxing sounds and infrequent checks by operating personnel are adequate to control problems with boxing. Operating of the 29 inch loom at Georgia Tech from a cold state over short run periods meant that the loom was not in an equilibrium state from the point of view of parts temperature and box to shuttle coefficient of friction, for example. Fortunately, the loom comes to a quasi-equilibrium quickly and therefore operates. Care should still be taken with respect to picking.

Finally in the loom patrol are the following points: 1.) inspection of yarns in the harnesses (behind the reed) for crossed or dropped ends, 2.) inspection of the shed on the front, 3.) inspection of both sides of the fabric, and 4.) timing the filling outage of the quill in the loom. Inspection around the reed will find a frayed warp yarn occasionally. Of a warp yarn is frayed behind the reed, the frayed filament will normally be pushed down the warp yarn as weaving advances the fabric. A repair is affected by breaking out the warp yarn on both sides of the reed and tying in a yarn segment saved for this purpose. The best knot for tying a repair yarn is the weaver's knot, if knot size and ability to be hidden is the only concern. With some continuous filament yarns the weaver's knot will slip. A double weaver's knot is offered as the next better step in reducing knot slip while holding minimal knot size. Figure 15 offers a selection of weaver's knots which are applicable to synthetic yarns. The single weaver's knot is certainly by far the most common in industrial practice. Figures 16 and 17 illustrate in four frames the tying of a common weaver's knot. DuPont industrial strength polyester yarns have some degree of rotoset entanglement or intermixing of the filaments. These will probably be the yarns woven for

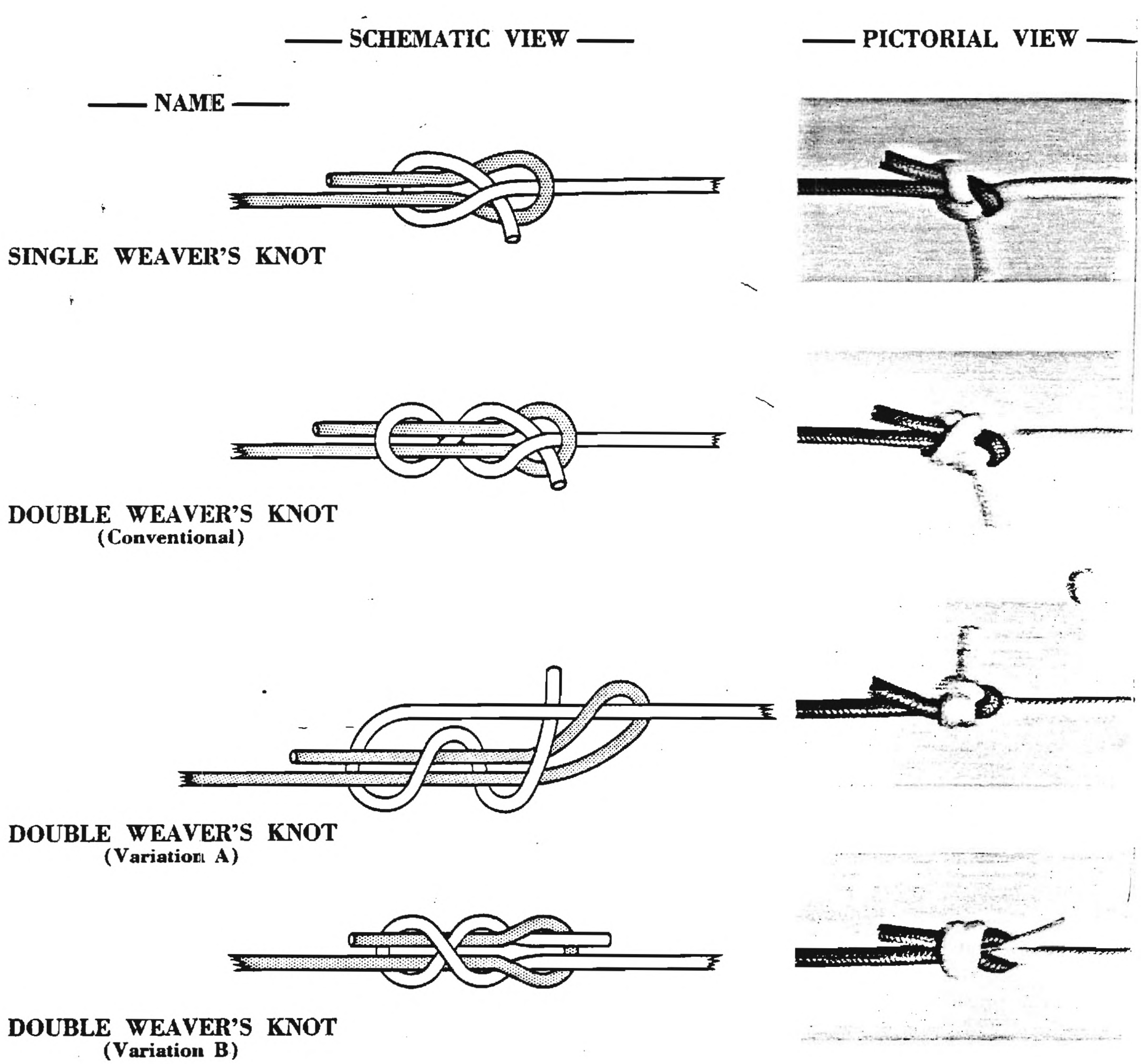


Figure 15. Knots for Synthetics

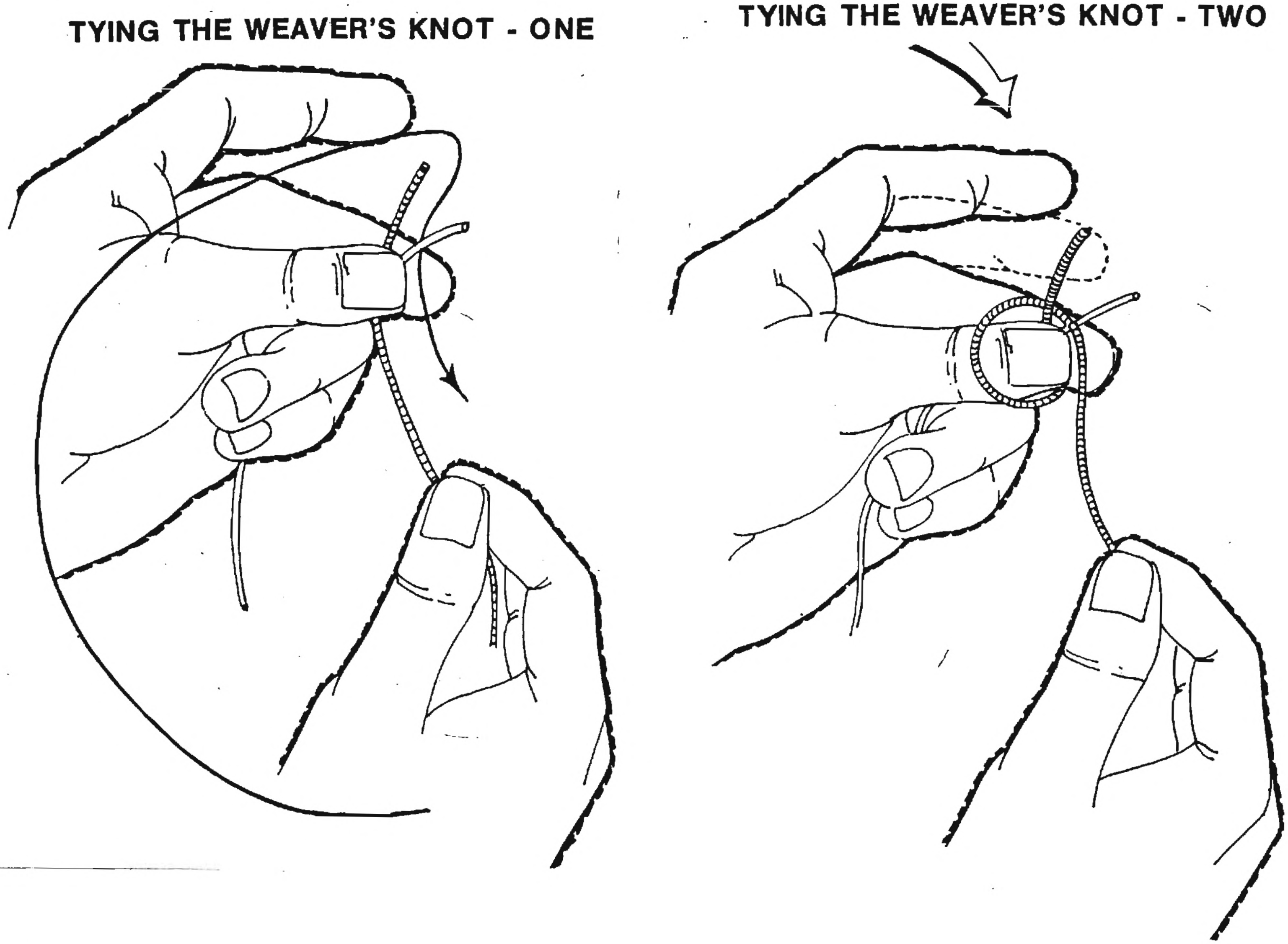


Figure 16. Tying the Weaver's Knot: 1-2

TYING THE WEAVER'S KNOT - THREE

TYING THE WEAVER'S KNOT - FOUR

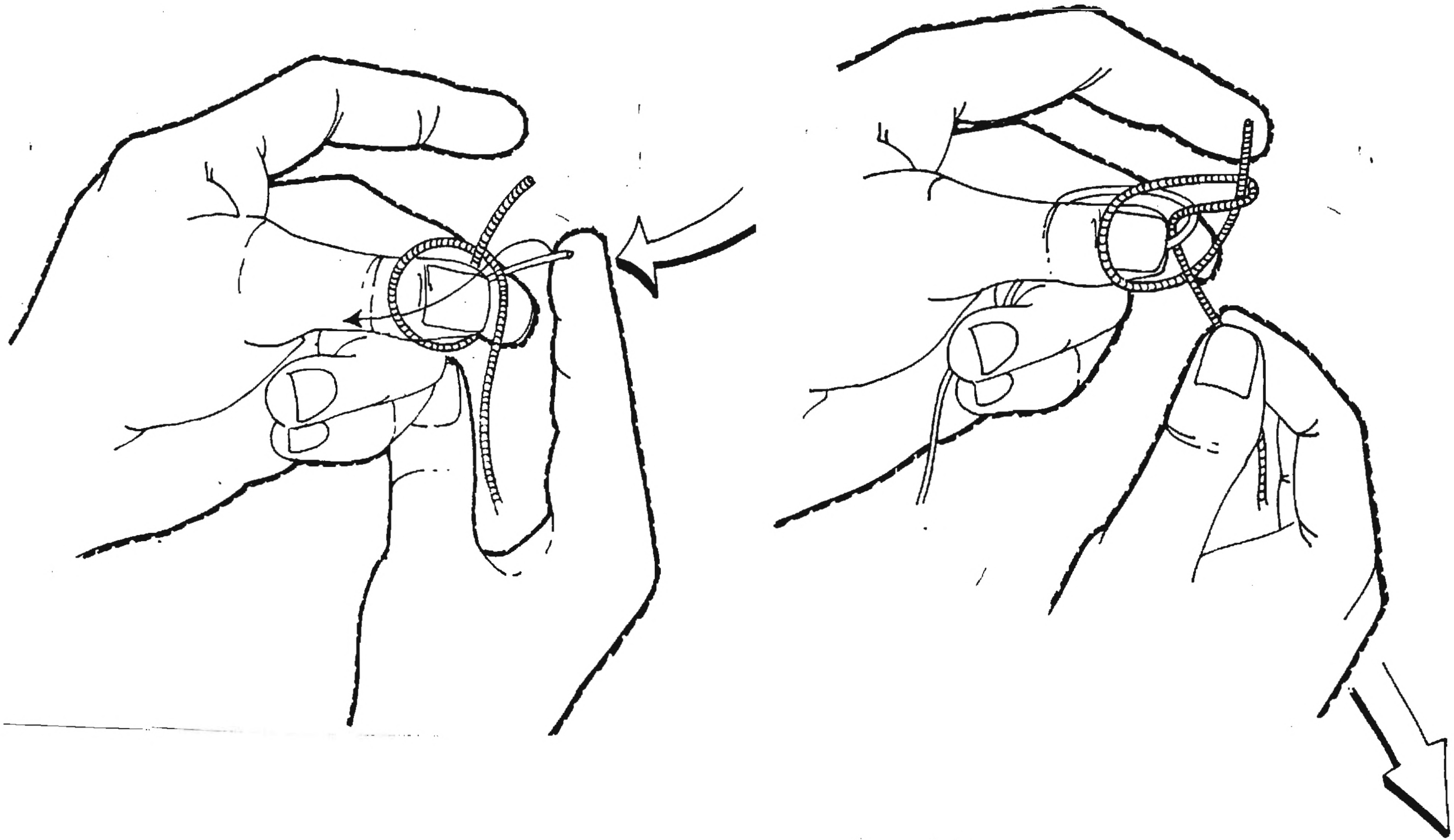


Figure 17. Tying the Weavers Knot: 3-4

tubular fabric specimens. The weaver's knot holds on this yarn with about 80% reliability and the double weaver's knot has held every time in the weaving experience with tubular fabric at Georgia Tech.

At every third filling quill change a visual inspection with a loupe (7x) is made for squares of the weave and defects. At the first quill change the ends and picks per inch are checked against specifications.

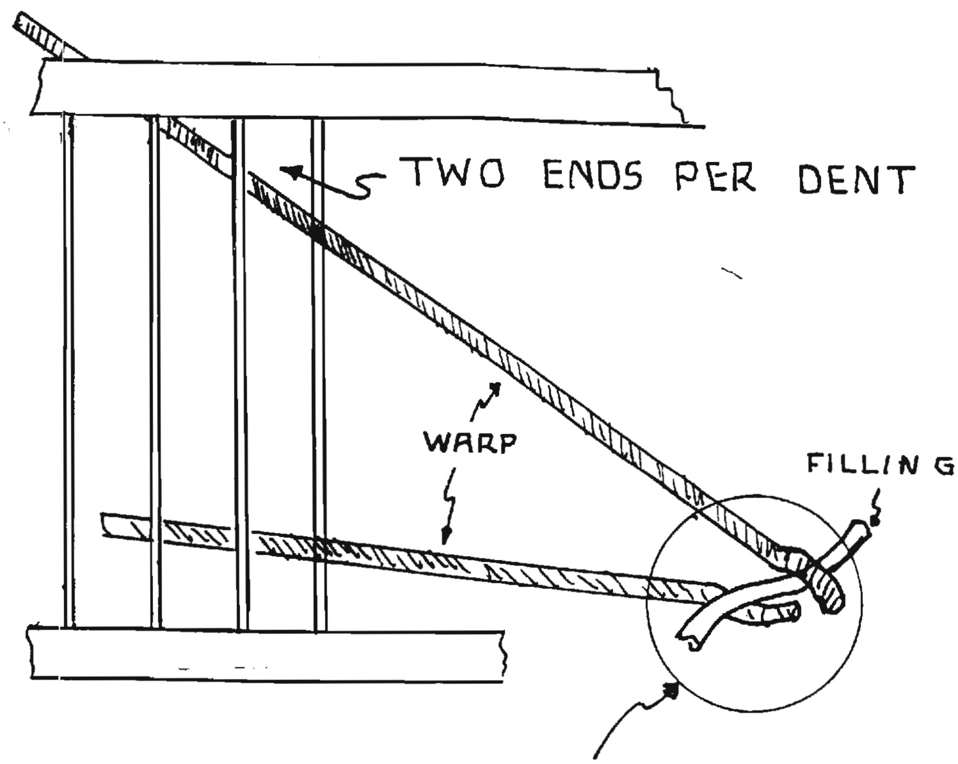
Because of warp tension on the loom, yarn crimp, which is normally balanced in a relaxed fabric between the warp and filling sets of yarns, is imbalanced - the crimp is greater in the filling yarn. When the fabric is removed from the loom, the warp will assume more crimp and the filling will release some crimp. The warp will be shorter than in the as woven, loom state. The filling direction will become wider. On loom experience with the 29 inch loom showed that the reed must be dented with 5% allowance for width expansion which decreases the warp ends per inch, i.e. the reed dents are more closely spaced by 5% than the fabric specification. Experience with warp contraction has shown that in contrast to any theoretical prediction the change was only 1/2 to 1% which is on the same order as the pick change gear increment, i.e. the limit of machine accuracy. This is probably due to having a lighter than normal warp tension.

Fabric quality checks on the loom include visual inspection for yarn irregularities, mispicks, and soiled spots. These are marked and corrected where possible. On a long run from a full beam the fabric may be cut from the cloth roll and inspected full circumference.

A notable defect in double fabric and tubular fabric weaving is the tight edge developed as the yarn in the shuttle begins payout. The tube is woven as two flat sheets with common edges. Payout forces are supported from the fabric edge opposite the direction of shuttle flight. Correction for this is carried out in the initial phase of loom operation. The rectification of a tight edge problem is by spreading the warp ends in the reed.

As a rule the limiting number of ends per reed dent to be assured that twisting of the warp ends across one another does not occur is equal to the pattern repeat length. Figure 18 shows how multiple ends per dent are held in correct spatial relation one to the other. Another consideration with respect to reeds is that increasing the number of dents decreases the strength and stability of the reed, as well as decreasing the total percentage of free space in the reed. On the 29 inch loom, the pattern was four picks in length and the reed draw was four ends per dent in a twenty dent per inch reed. A dent in this usage is the space between the comb-like teeth of the reed.

To spread the edge warp a new tapered pattern for the edge draw in the reed is selected. Generally, a two end draw in two outside dents is workable for the 29 inch loom example given above. Shuttle eye tension clearly affects the fabric edge density. Rather than a 2-2 draw, a 2-2-2-1-



- INTERLACING PLACES TWO YARNS IN CORRECT LEFT-RIGHT ORDER
- DOUBLE / TUBULAR FABRIC ALLOWS TWO ADDITIONAL WARP ENDS PER REED DENT

Figure 18. Multiple Ends Per Dent

1 draw may be attempted. The fabric has to be woven over to the cloth roll in sufficient length for handling, cut from the loom, and subjected to combined shear and tensile forces to adequately determine that the edge defect is imperceptable. During discussion of edge tightness, thought was given to leaving the tight edge as it was and aligning it along space suit joint constraint lines. The constraint line is the region of least deflection. A counterargument to this was that the alignment presents the opportunity for assembly error that a uniform fabric would avoid.

A last footnote to loom operation is that while fabrics are usually centered in the loom and in the reed space, special circumstances control narrow fabric weaving. Each flight of the shuttle must withdraw filling yarn to assure uniform yarn tension from pick to pick. The amount withdrawn should be balanced on left or right picks for best fabric symmetry. Therefore, all of NASA test fabrics are woven on the centerline determined by shuttle eye position in both the left and right hand boxes. Tests to confirm the weavability of small diameters proved that fabrics down to 1 1/2 inch diameter could be produced on the 29 inch loom so long as the shuttle eye centerline was held as the fabric centerline. Of course, the shuttle flight must also be true.

X. Post-Weaving Treatment

Woven fabrics traditionally have a size applied to the warp yarns which must be scoured from the fabric. The NASA fabric specimens are woven unsized. Nevertheless, the yarns have producer's finish on their surface, which aided their passage through weaving. This can be removed most effectively with solvent cleaning, but at the risk of swelling the basic polymer structure of the fiber and modifying fiber properties. A recommended scouring method is to use a clear rinsing laboratory glassware detergent in cold water. Polyester is hydrophobic and reacts extremely slowly in cold aqueous systems. Clear rinsing detergents leave very little residue. The result is a substrate prepared for coating with as little chance as possible of fiber finish interference with coating adhesion. A side benefit is that the fabric is cleaned of smudges or fingerprints as well, i.e. cosmetic cleaning.

No heat treatment or ironing should be given to press out wrinkles. While polyester does take a second or third heat treatment so long as the temperature of the last treatments exceeds previous treatments, the shrinkage of the fabric for molding is not recoverable if removed by earlier heat treatment. DuPont Type 55 and Type 68 polyesters have been given heat treatments at 395^{O}F over various molds, e.g. rolling convolute and toroidal shapes, for shrink fit forming. So long as the producer's finish was scoured from the fabric, discoloration was not observed. Heat treatment times ranged from five to fifteen minutes. Tests showed that Type 55 had shrinkage of about 15% and Type 68 had shrinkage of about 12%. If in post treatment the fabric was immersed in water of hot scour temperature range of 180-

210°F (80-100°C), then molding shrinkage was reduced by 50% on average.

Once scoured there is essentially no finish to "bind" filaments together. The fabric is more subject to picking of individual filaments by burrs on equipment used in later fabric handling. After coating, this tendency can be reversed on the uncoated surface somewhat by spraying the fabric surface with a soil release agent, such as the 3M "Scotchguard" product.

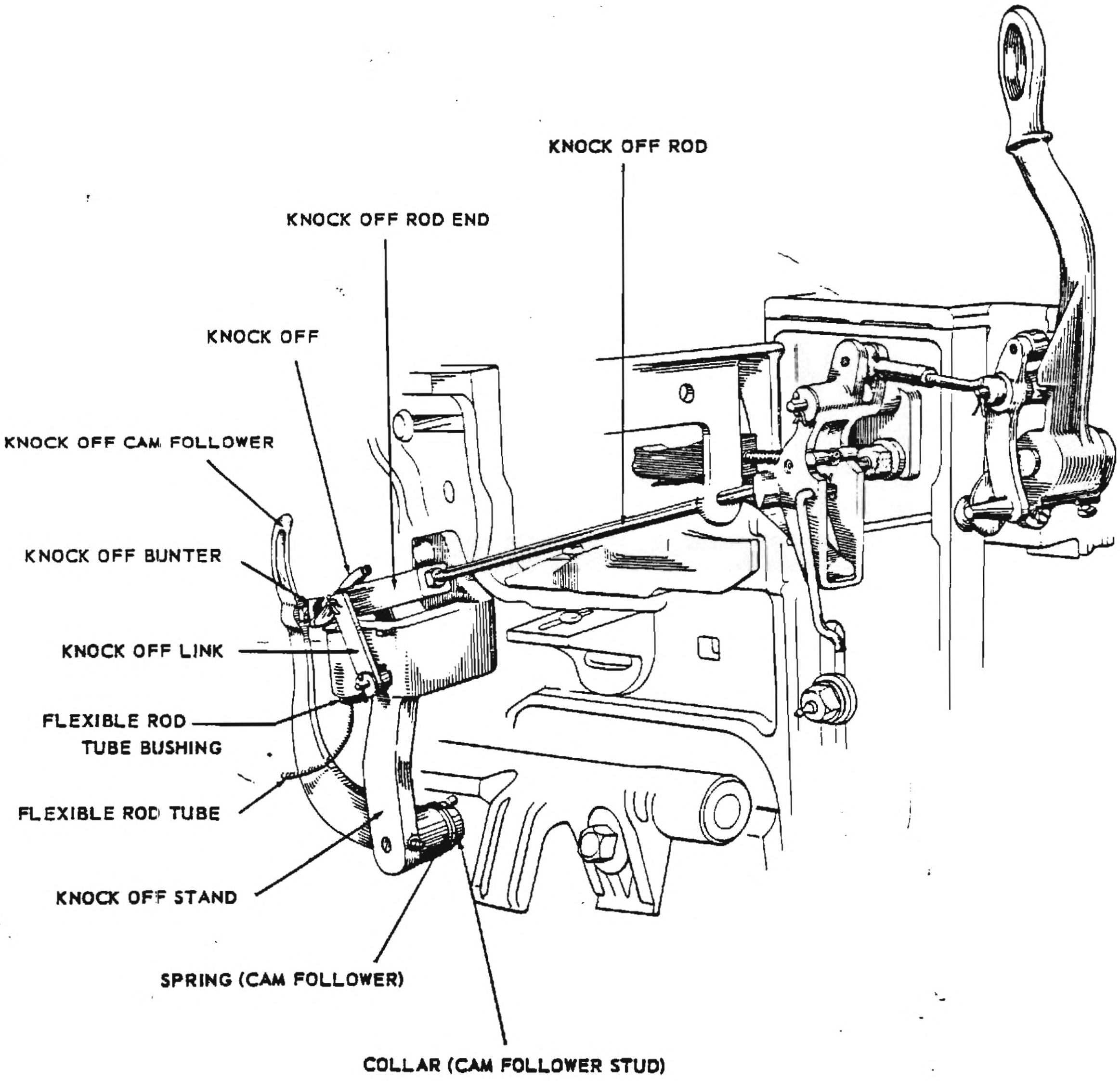
XI. Summary

The preparation for weaving, weaving itself, and post-weaving treatment of fabrics have been discussed from the point of view of special runs of small diameter tubular fabrics. The experience for many of the comments was gained in a research program sponsored by NASA for the development of molded, continuous tubular fabric joints for the NASA space suit. The technical monitor at NASA-JSC for this report was Joe Kosmo. The jointly decided purpose behind preparing an "experiences" document or recipe book was to attempt to assure propogation of what was learned while making these special fabrics. Appendices have been added which include out of print Draper documentation on the X series of looms. These contain fundamental insight into loom setup. The text contains notes, observations and test results which are related to the special nature of the NASA 29 inch Draper X-2 loom located at Georgia Tech. An additional appendix has been added to cover pertinent test methods for evaluation of fiber, yarn and fabric specimens from this work.

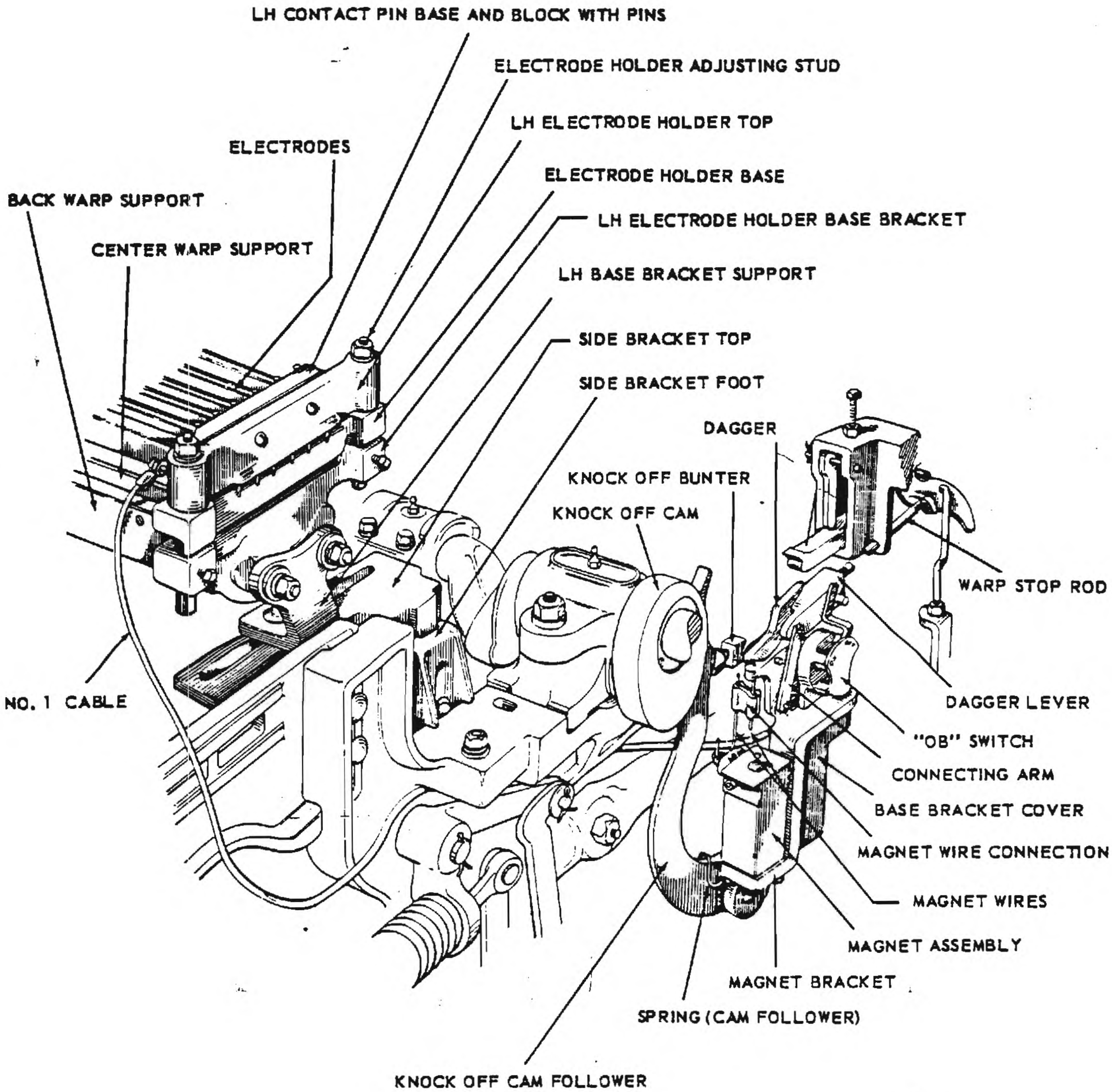
APPENDIX A

Draper X-2 Loom
Parts Identification

#28-R knock-off



WARP STOP MOTION

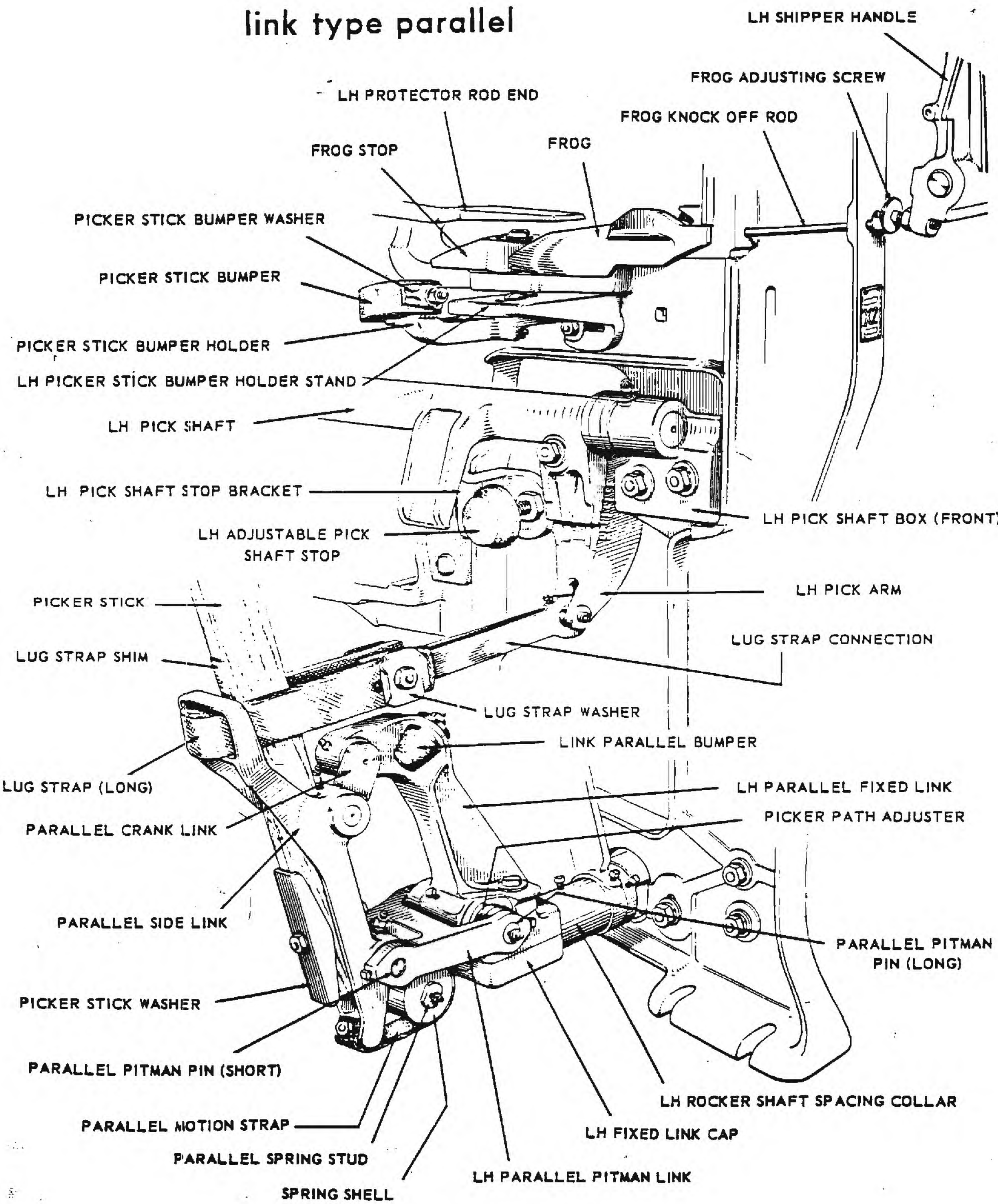


K-A electrical warp stop

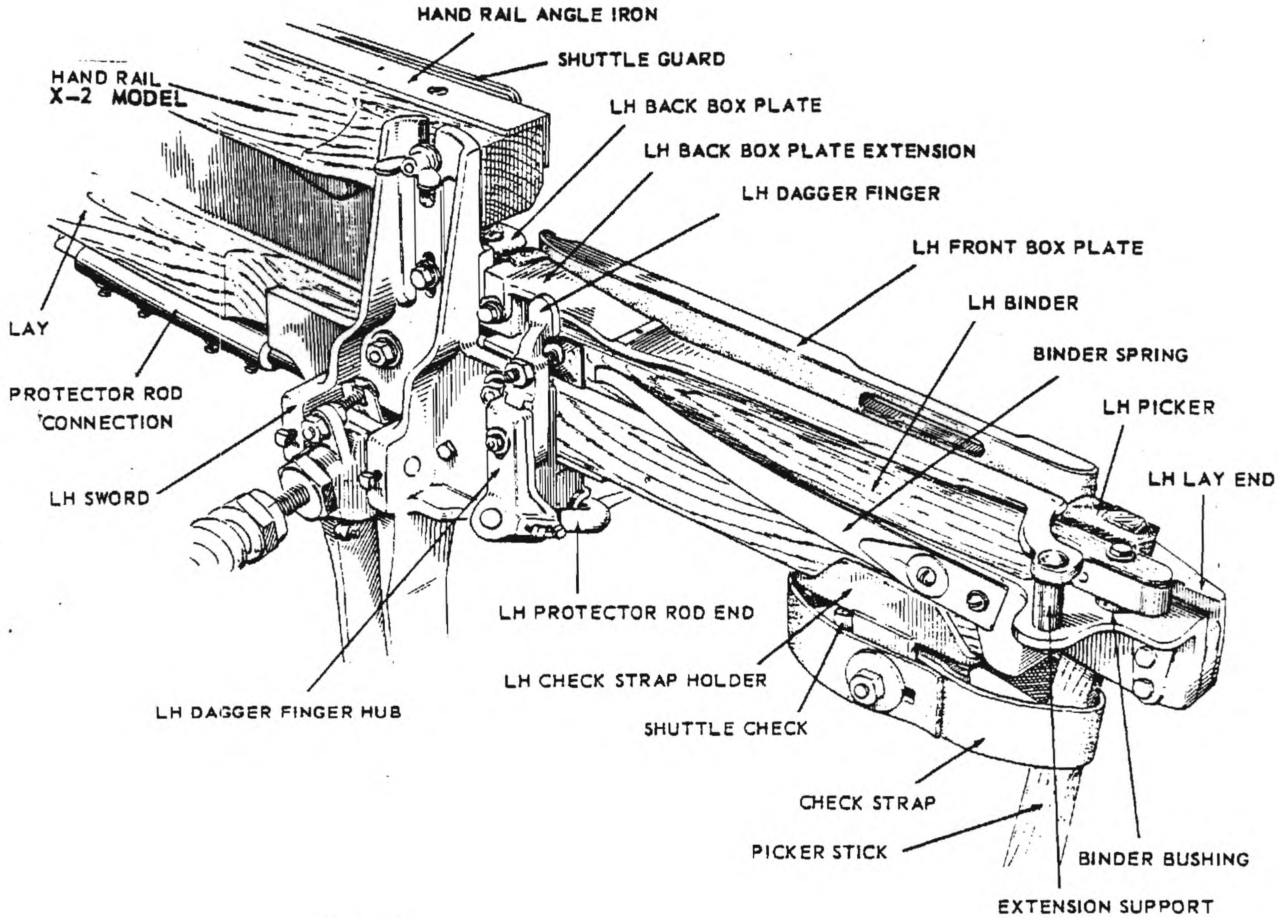
#27-R knock-off

WARP STOP MOTION

link type parallel



PARALLEL MOTION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SHUTTLE GUARD
HAND RAIL
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LH FRONT BOX PLATE
LH BINDER
BINDER SPRING
LAY
PROTECTOR ROD
CONNECTION
LH PICKER
LH LAY END
LH SWORD
LH PROTECTOR ROD END
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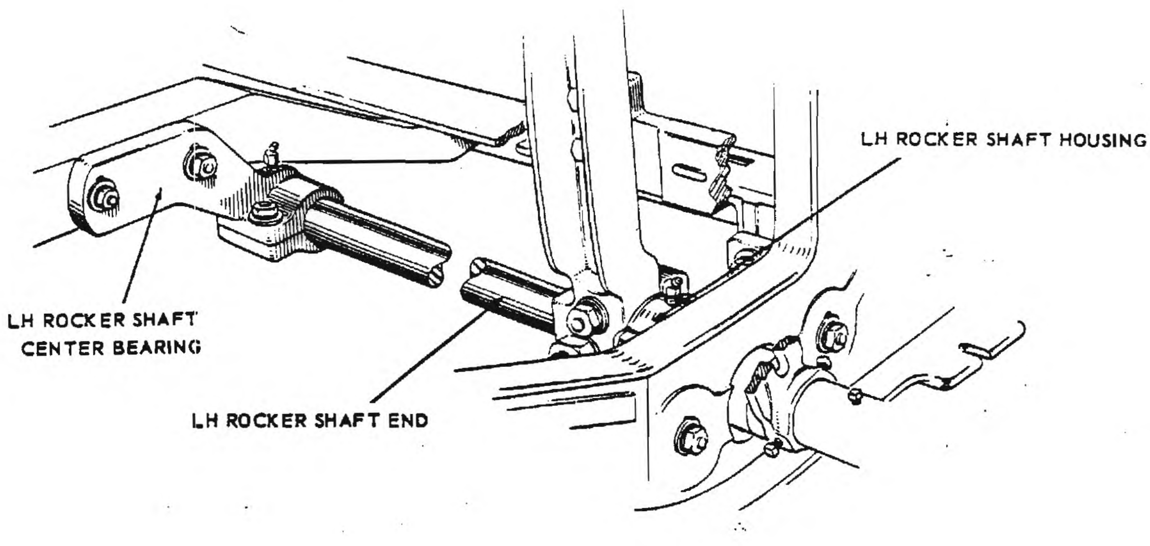
SHUTTLE CHECK
CHECK STRAP
PICKER STICK
BINDER BUSHING
EXTENSION SUPPORT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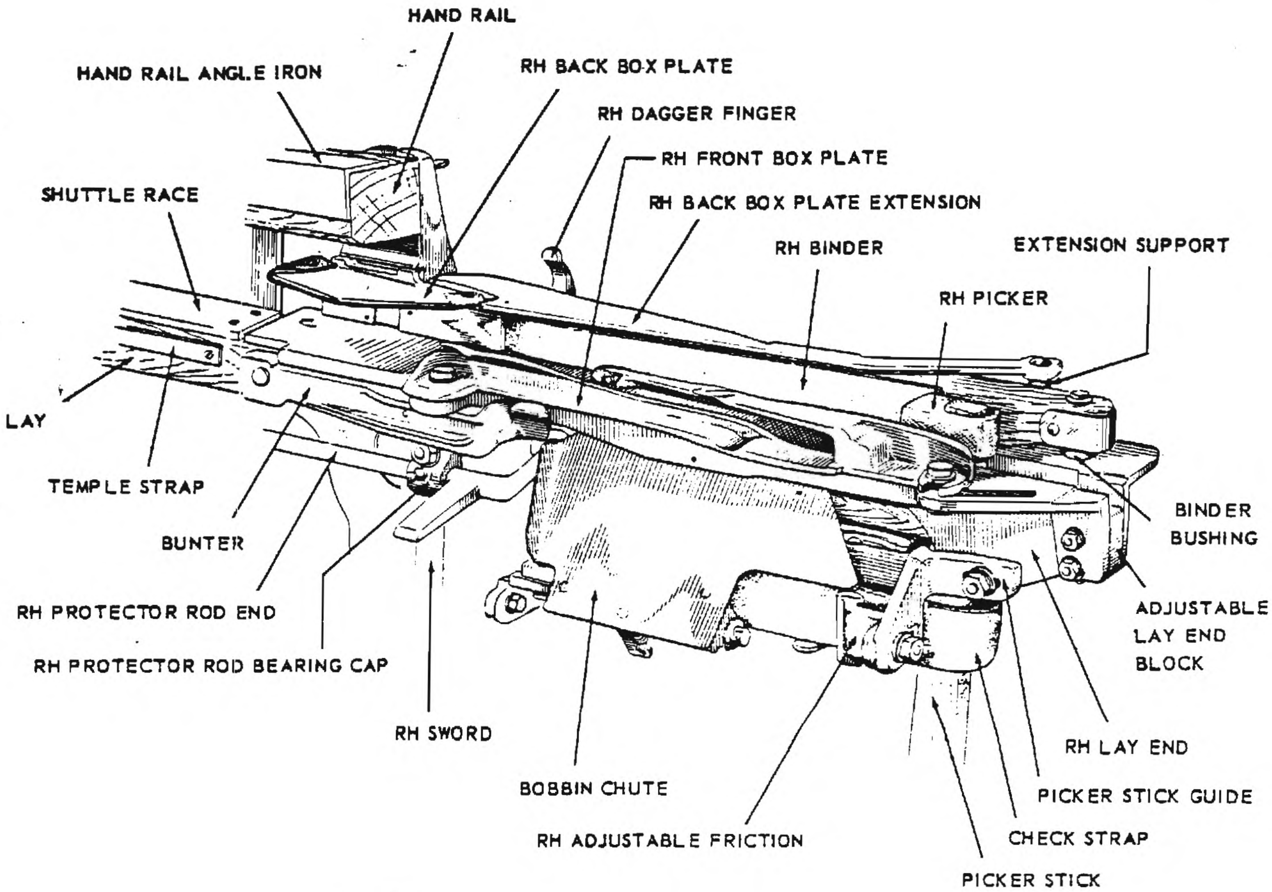
LH ROCKER SHAFT
CENTER BEARING
LH ROCKER SHAFT END

LAY PARTS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SHUTTLE RACE
RH BACK BOX PLATE EXTENSION
RH BINDER
EXTENSION SUPPORT
RH PICKER
LAY
TEMPLE STRAP
BINDER
BUSHING
BUNTER
ADJUSTABLE
LAY END
BLOCK
RH PROTECTOR ROD END
RH PROTECTOR ROD BEARING CAP
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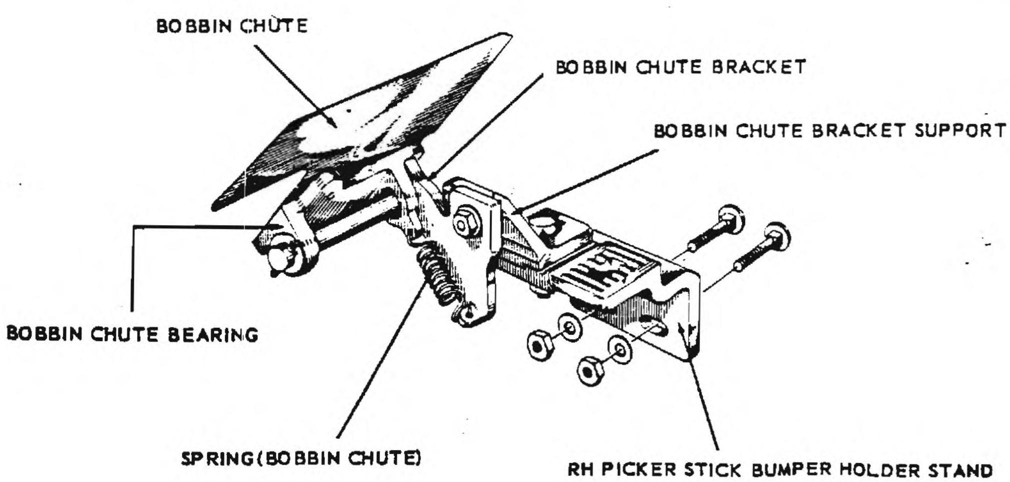
RH LAY END
BOBBIN CHUTE
PICKER STICK GUIDE
RH ADJUSTABLE FRICTION
CHECK STRAP
PICKER STICK


BOBBIN CHUTE
BOBBIN CHUTE BRACKET
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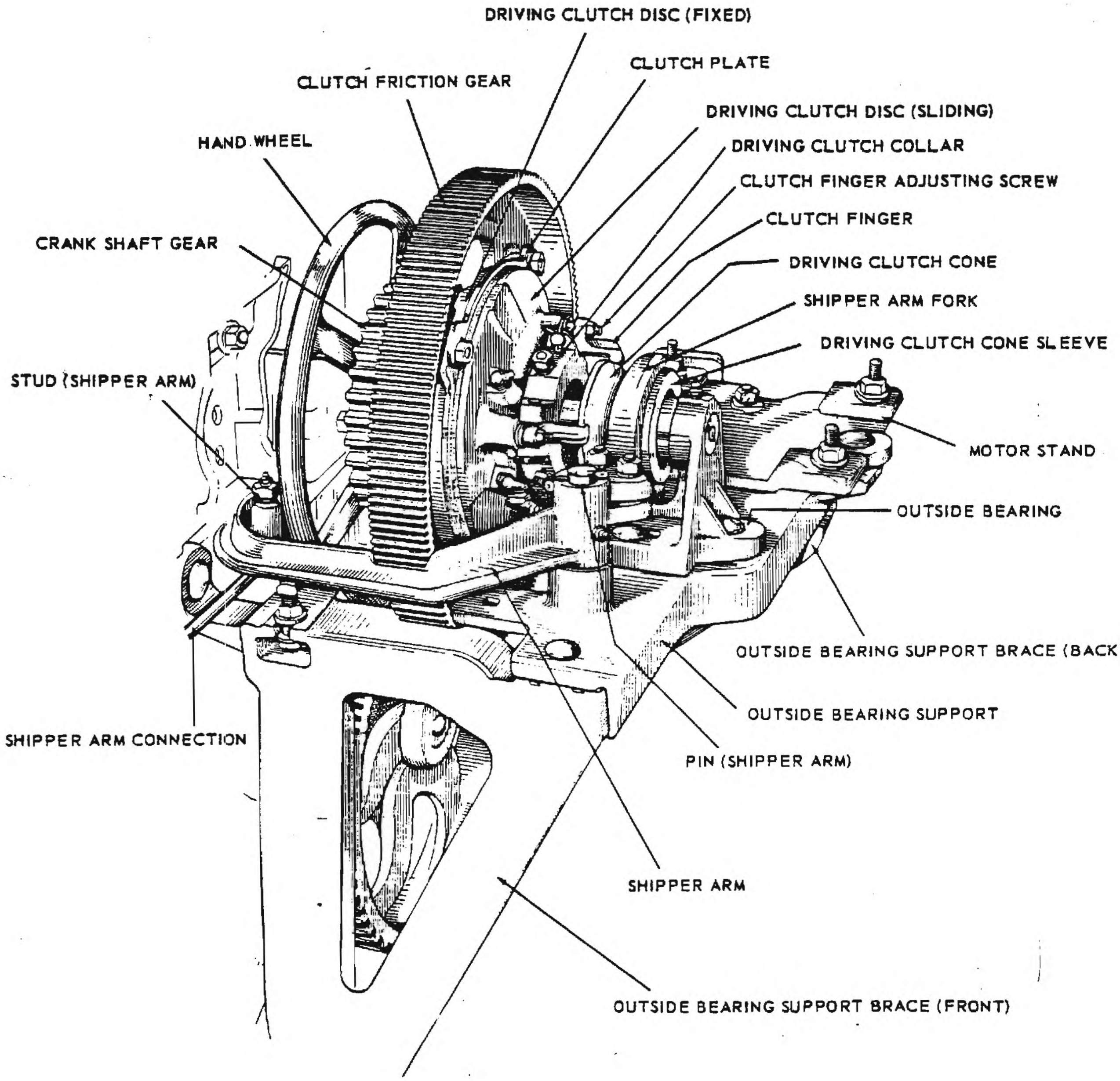
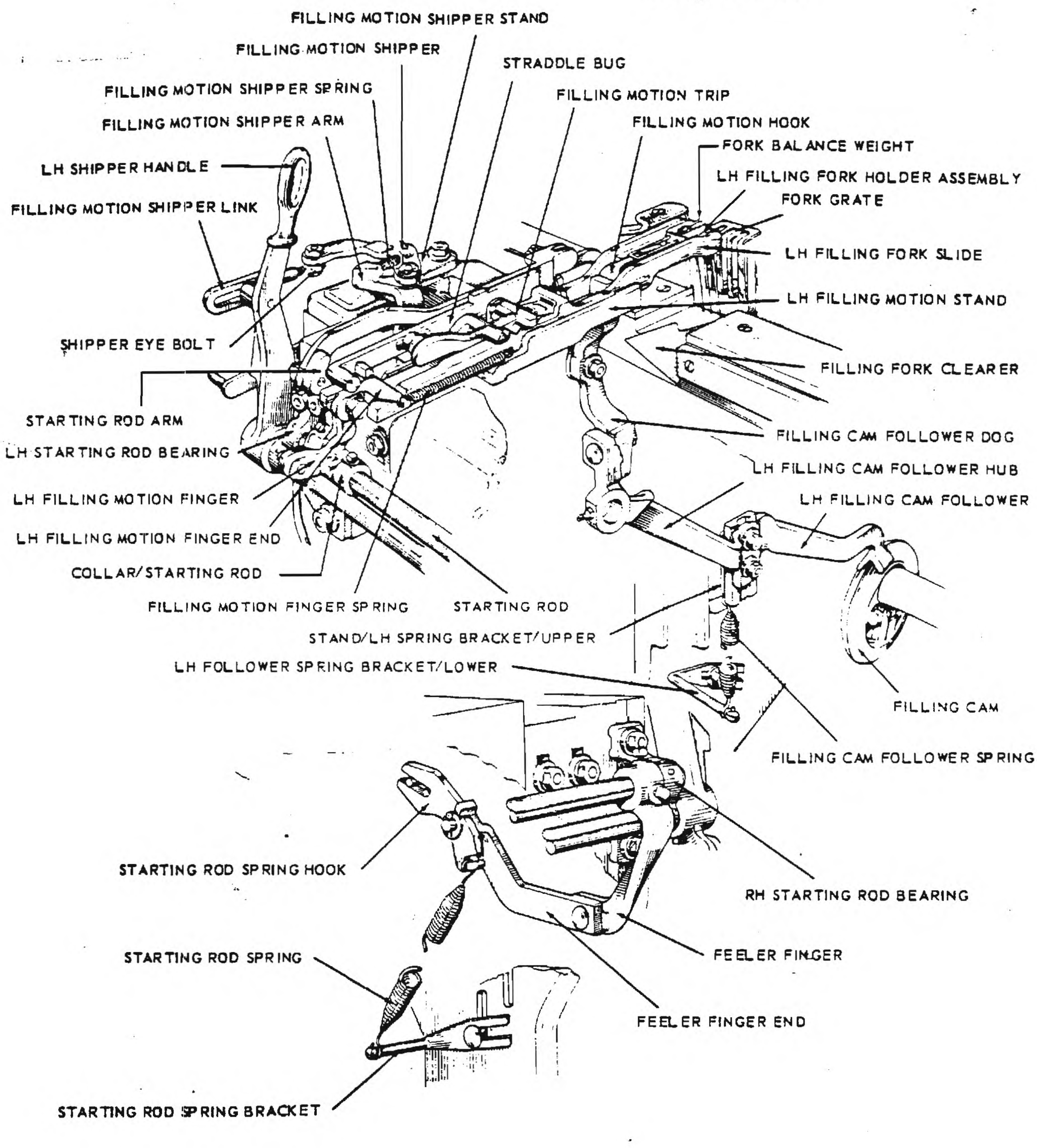
BOBBIN CHUTE BEARING
SPRING(BOBBIN CHUTE)
RH PICKER STICK BUMPER HOLDER STAND

LAY PARTS



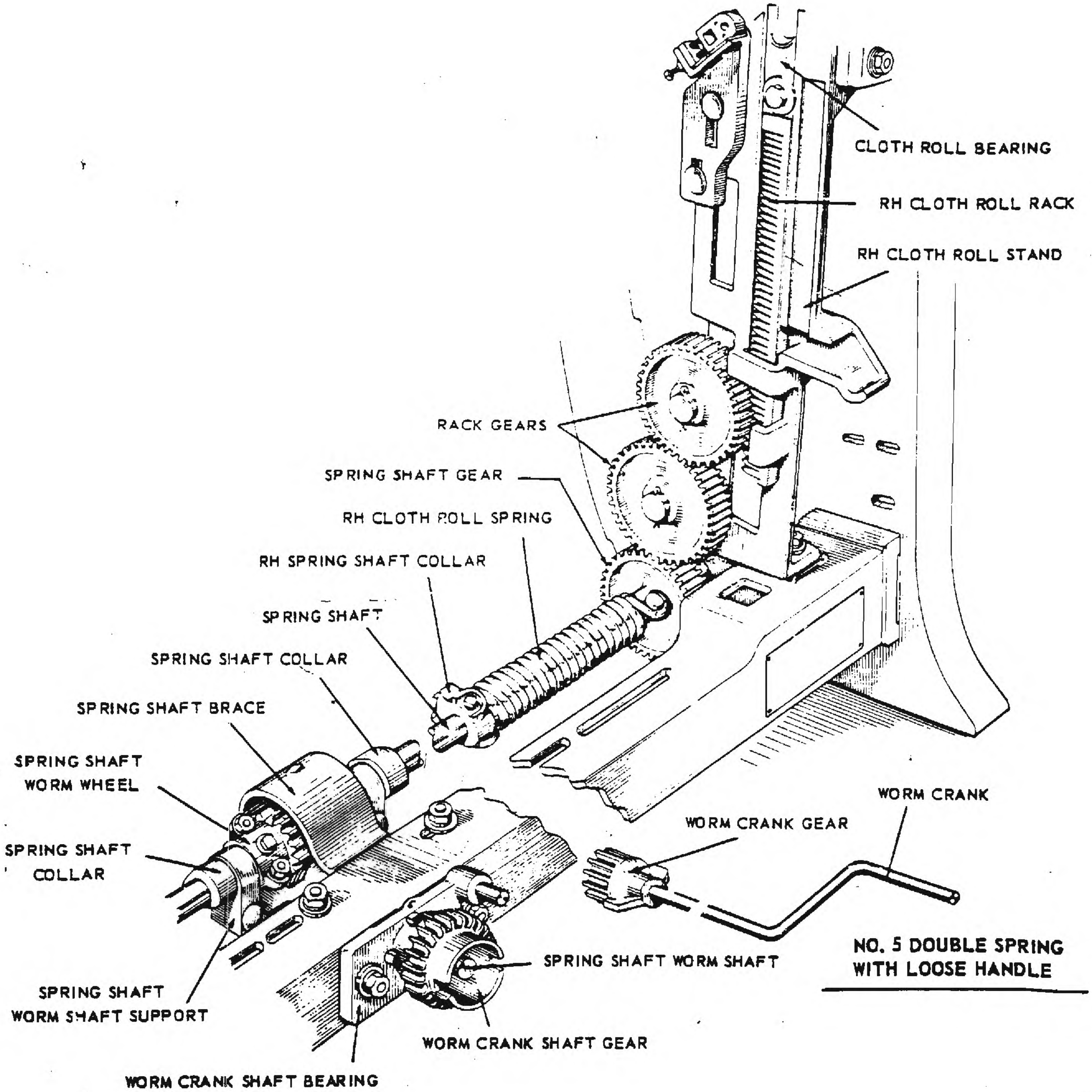
#8 dry disc clutch

single fork



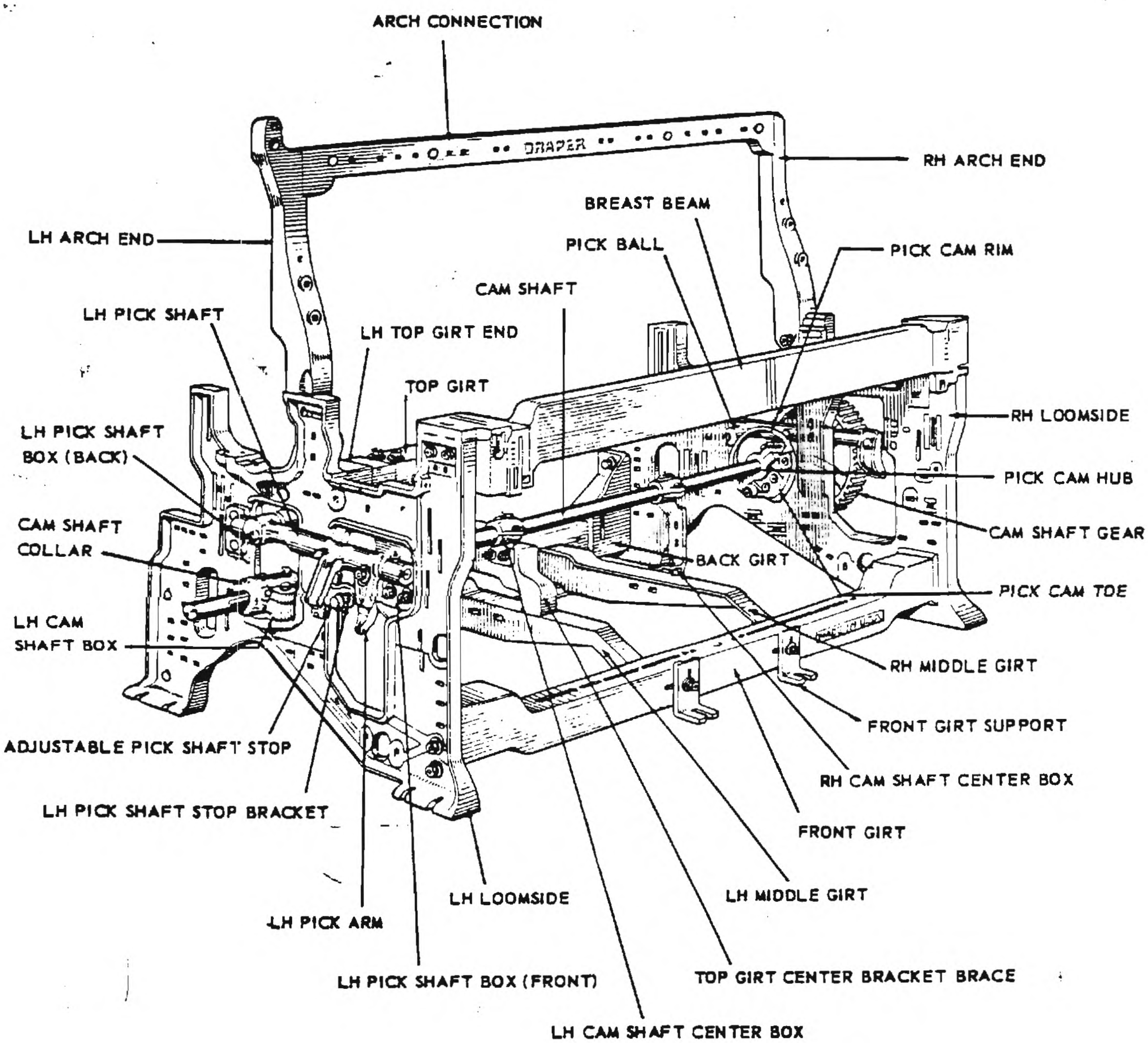
FILLING MOTION

wind-up for worm take-up

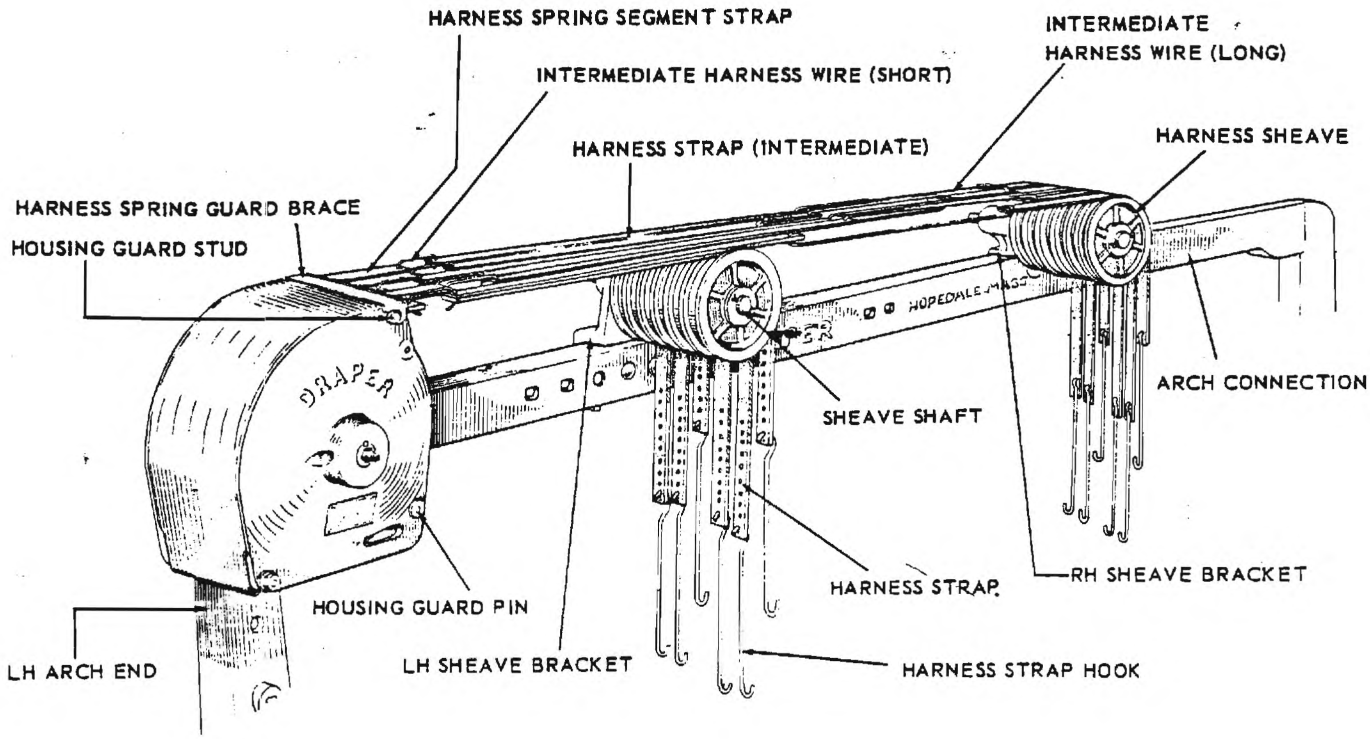


NO. 5 DOUBLE SPRING WITH LOOSE HANDLE

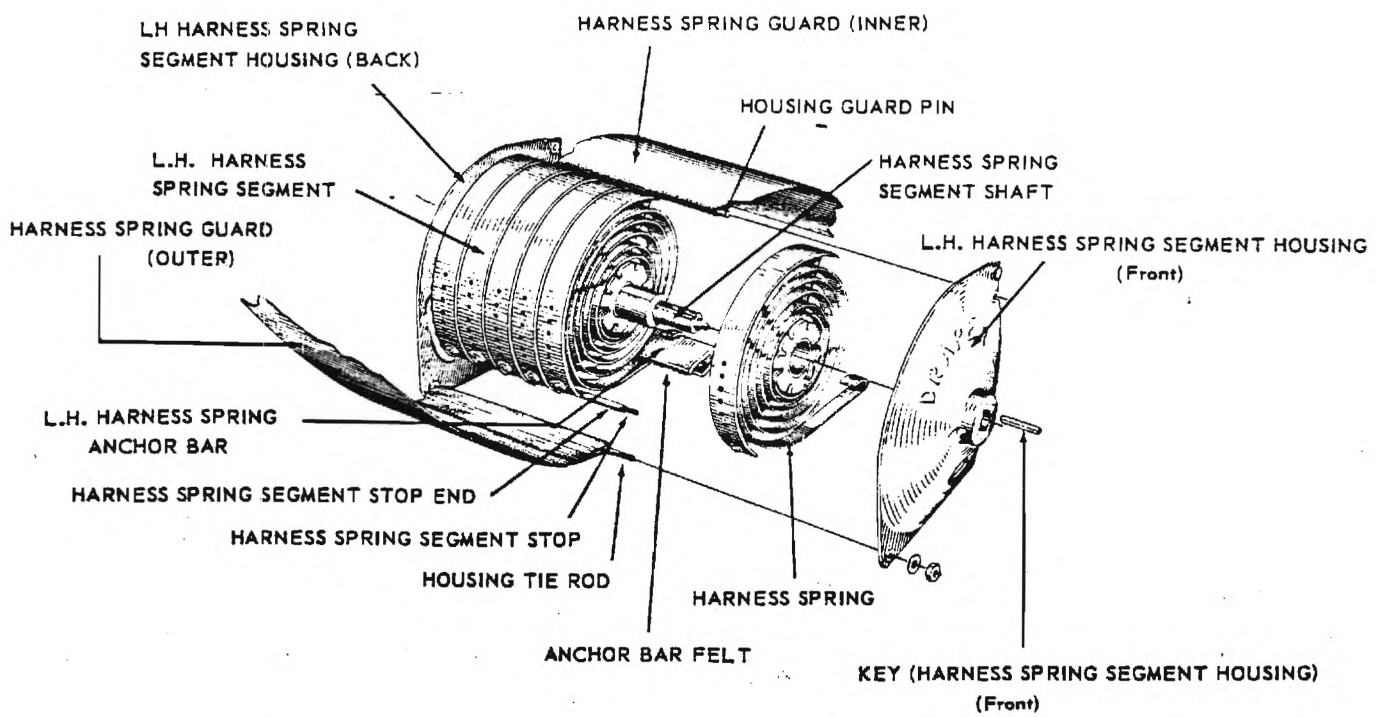
TAKE-UP MOTION



FRAME & PICK MOTION

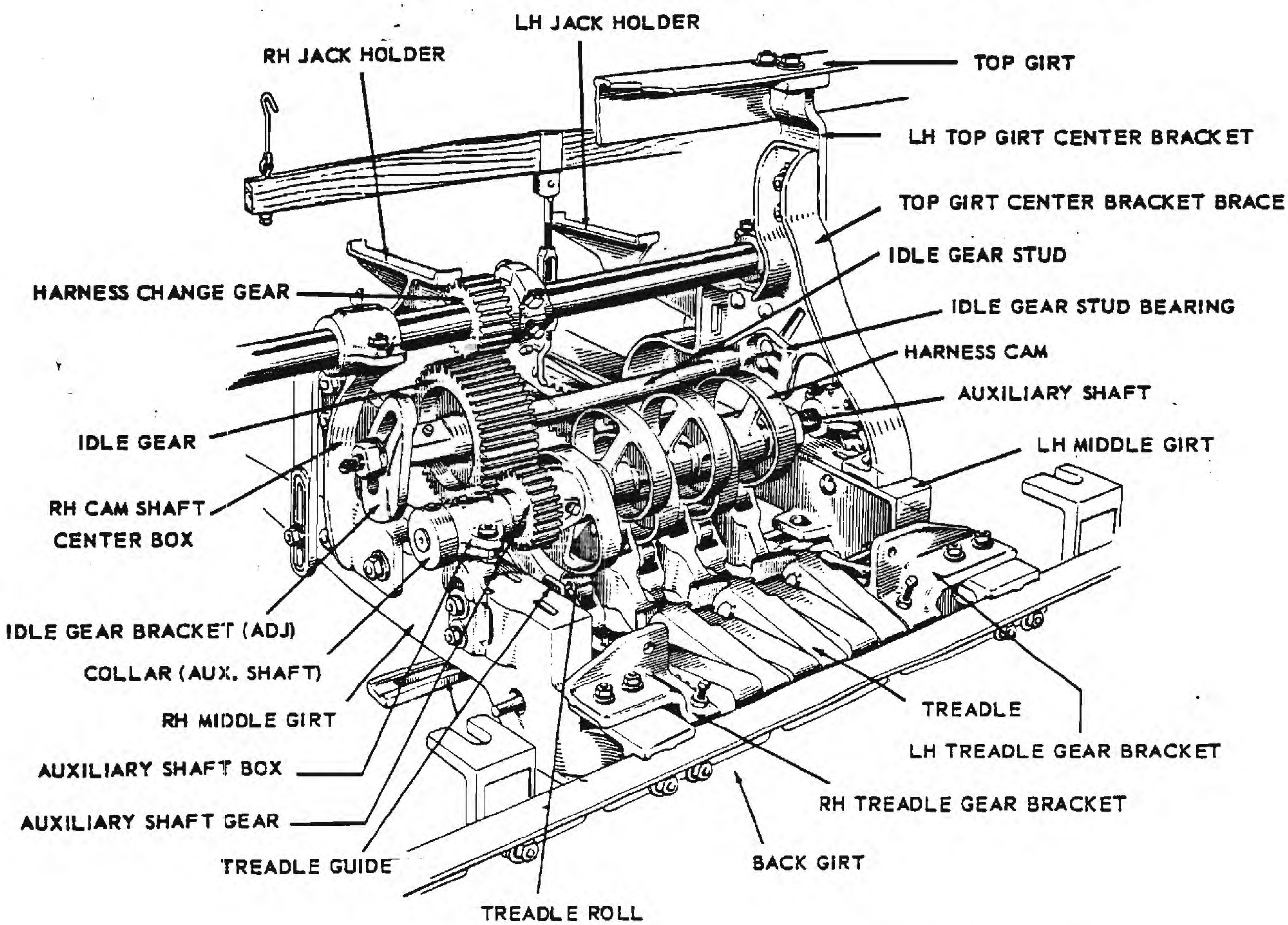


clock spring top

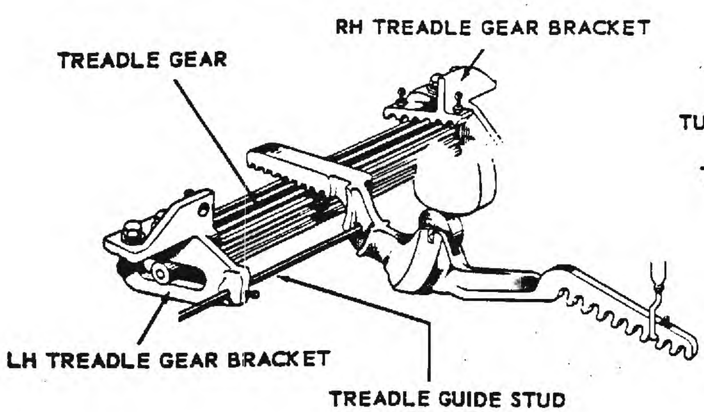


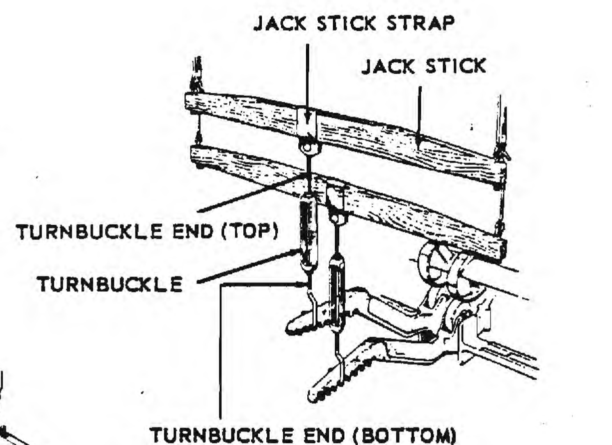
HARNESS MOTION

cams on auxiliary shaft



ADJUSTABLE TREADLES

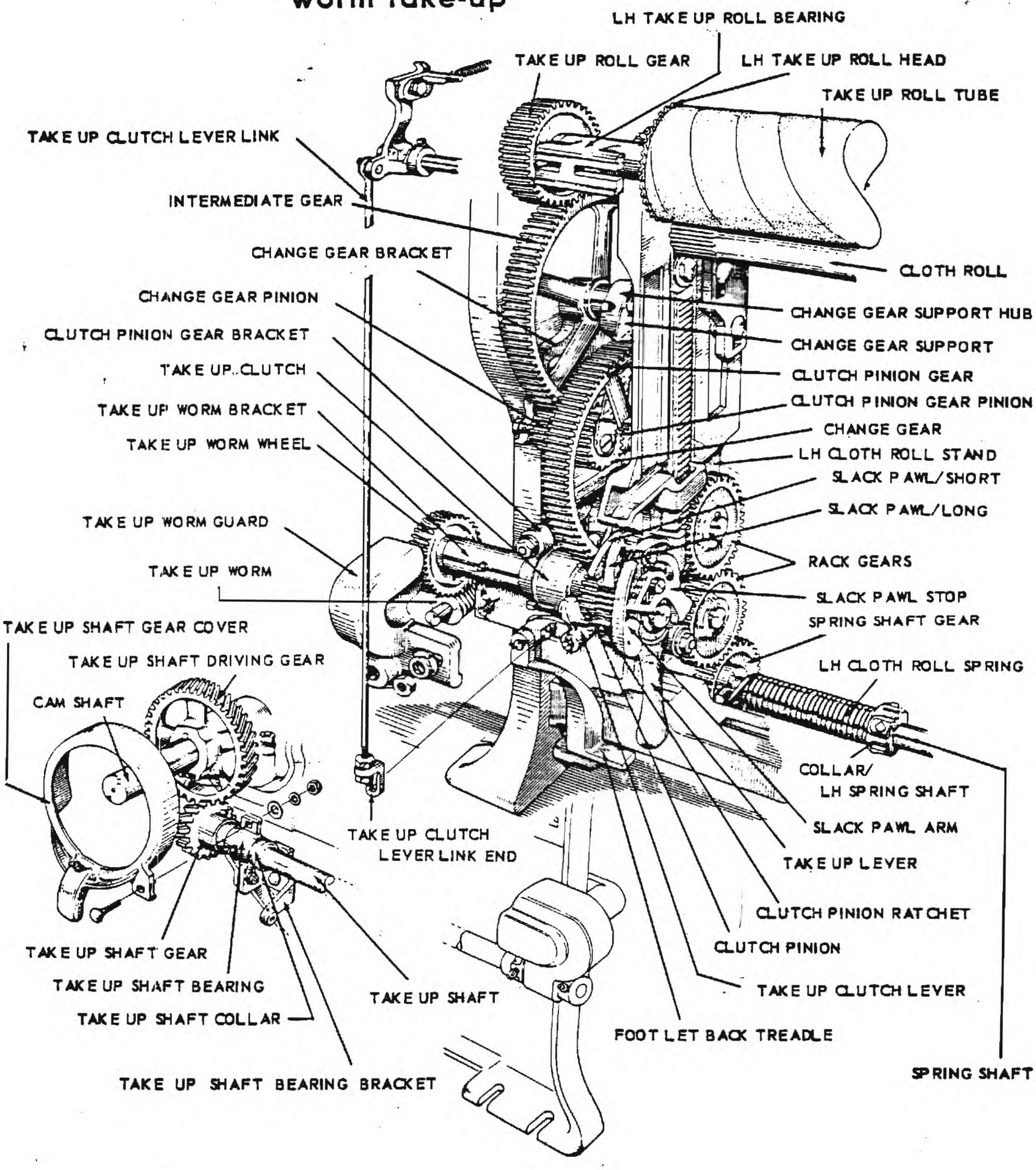




POSITIVE PULL-DOWN

HARNESS MOTION

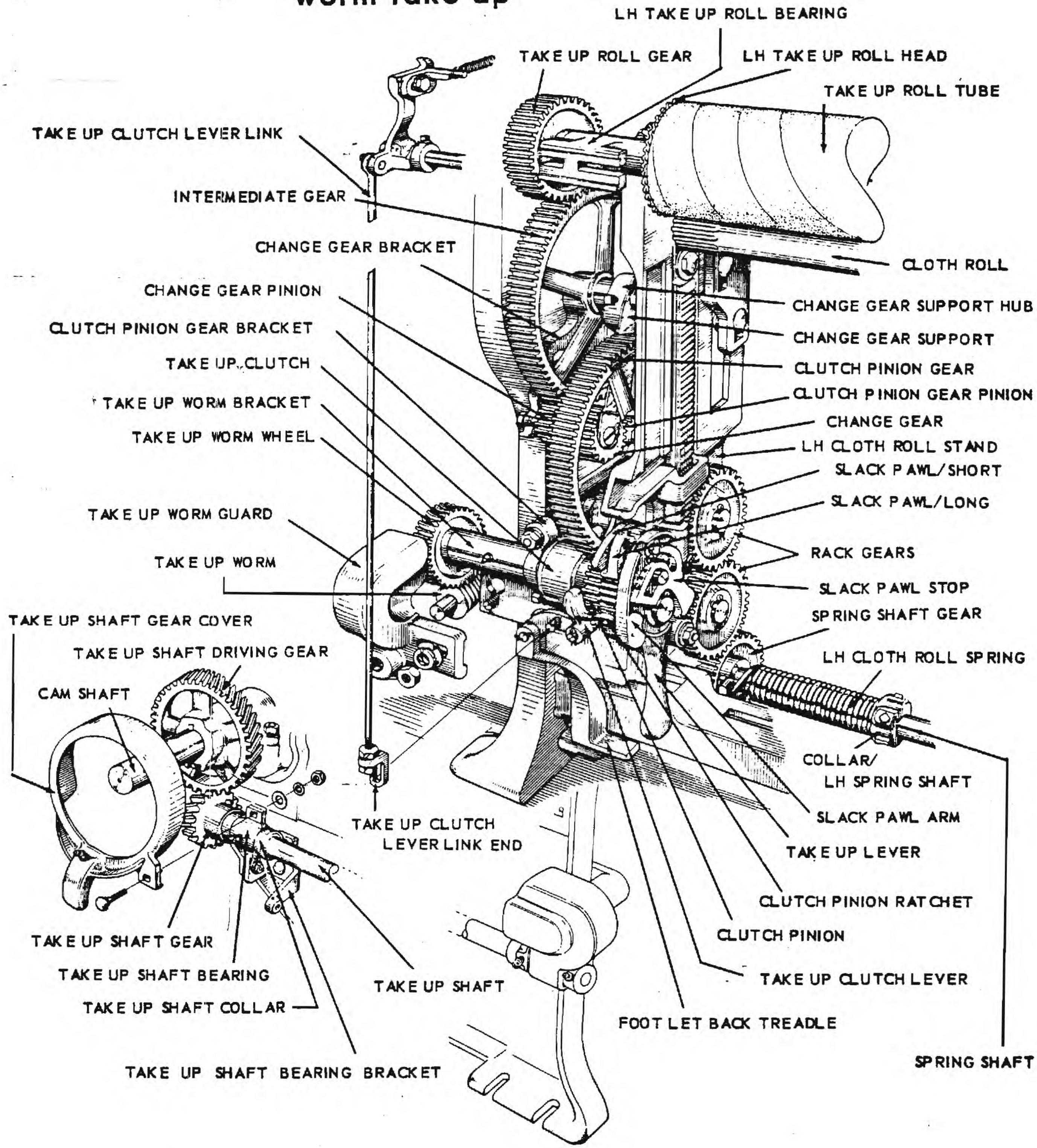
worm take-up



TAKE-UP MOTION

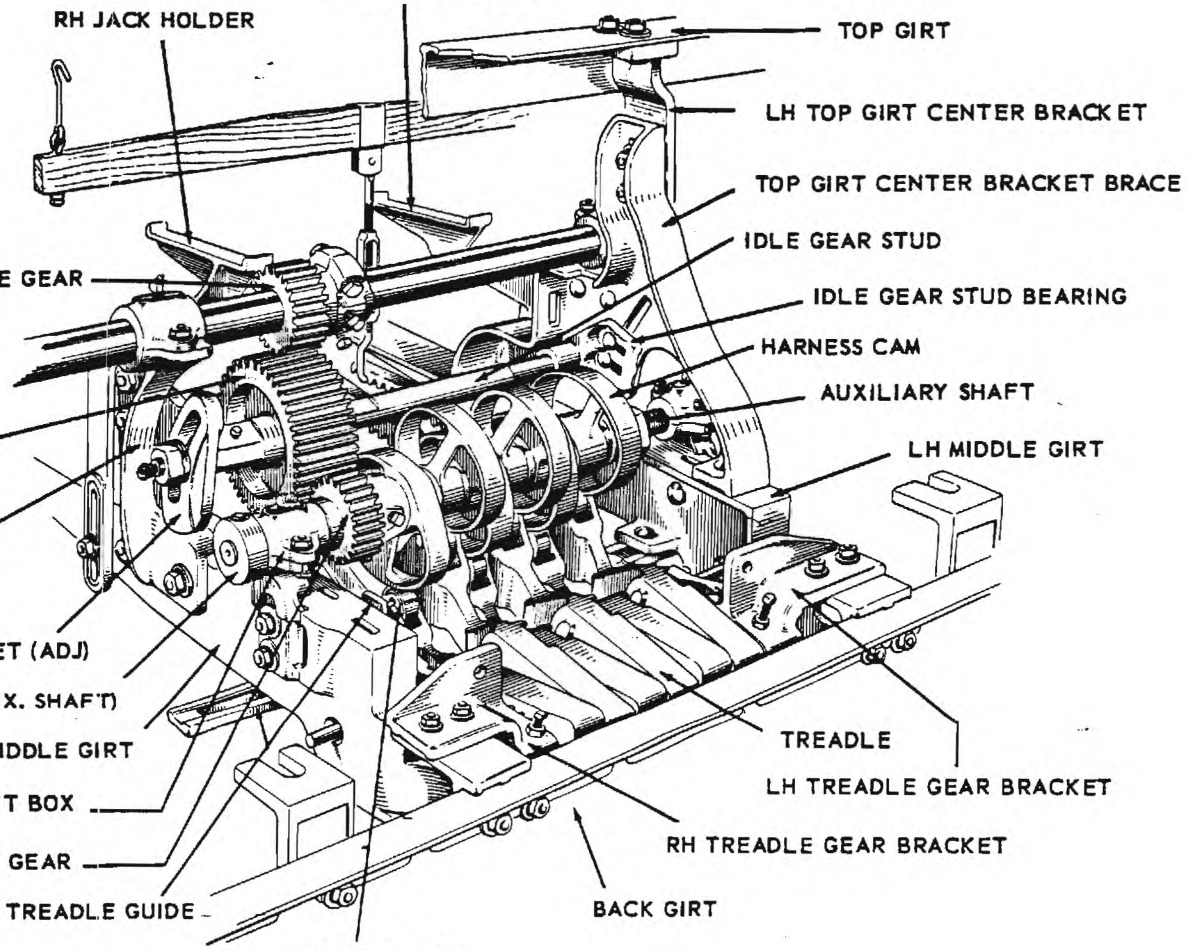
APPENDIX A

worm take-up



TAKE-UP MOTION

cams on auxiliary shaft



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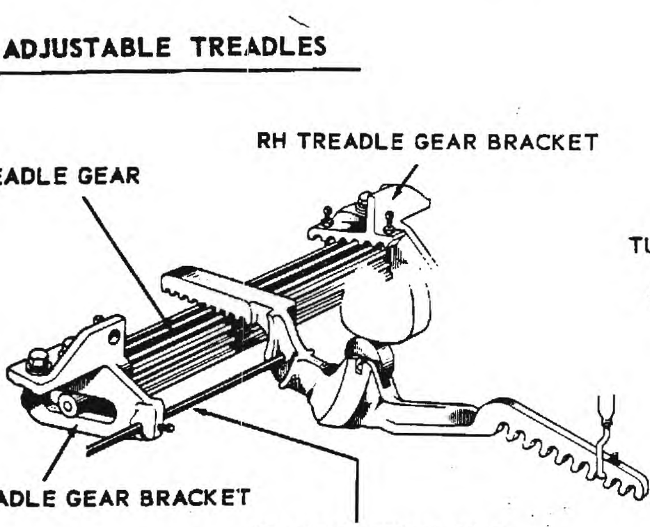
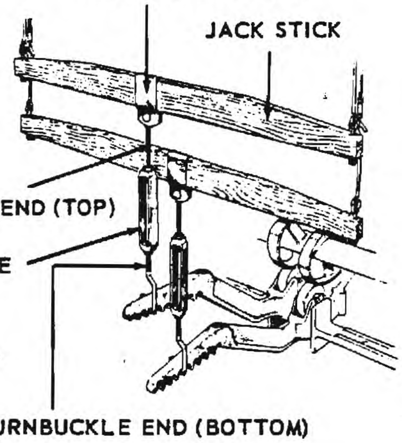
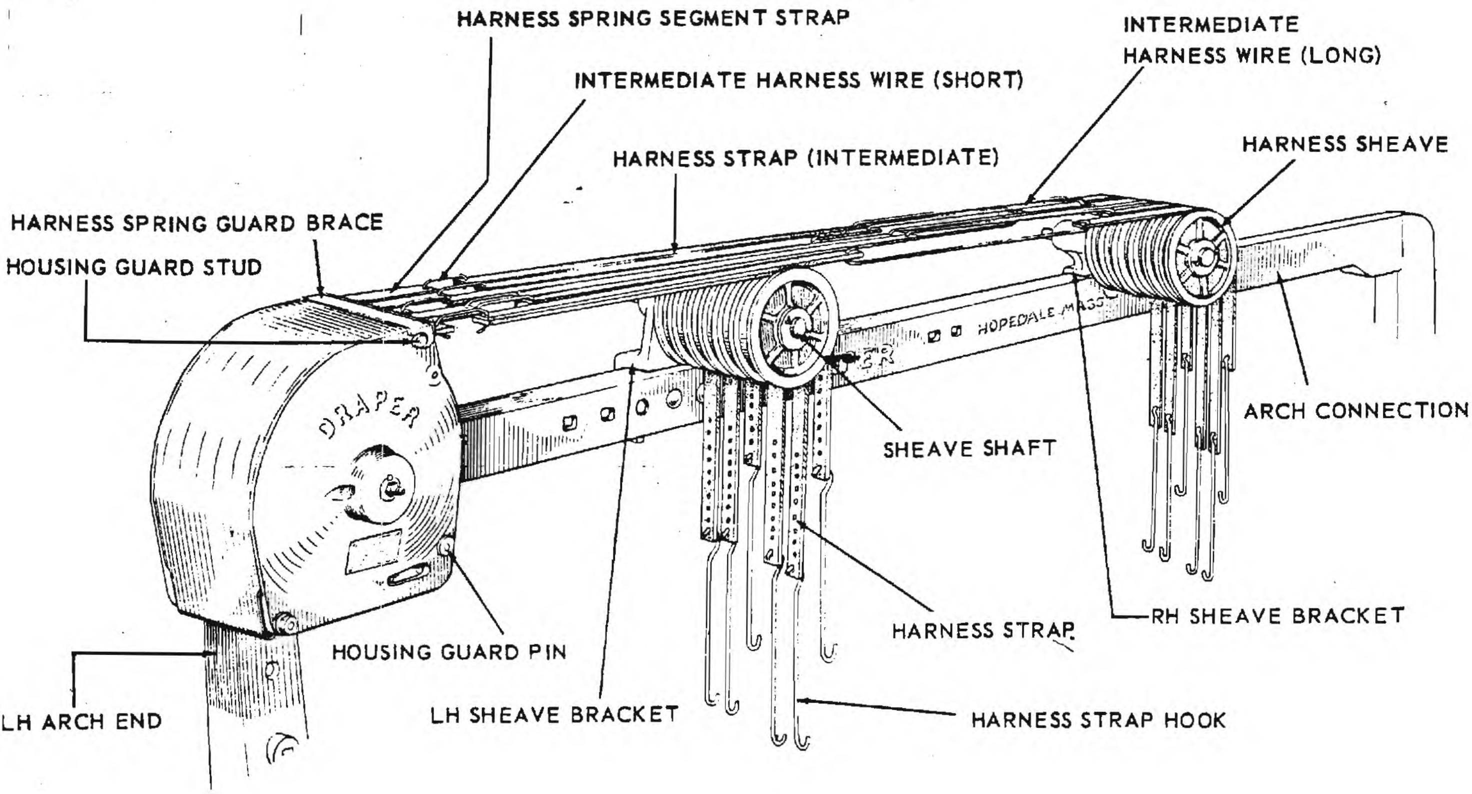


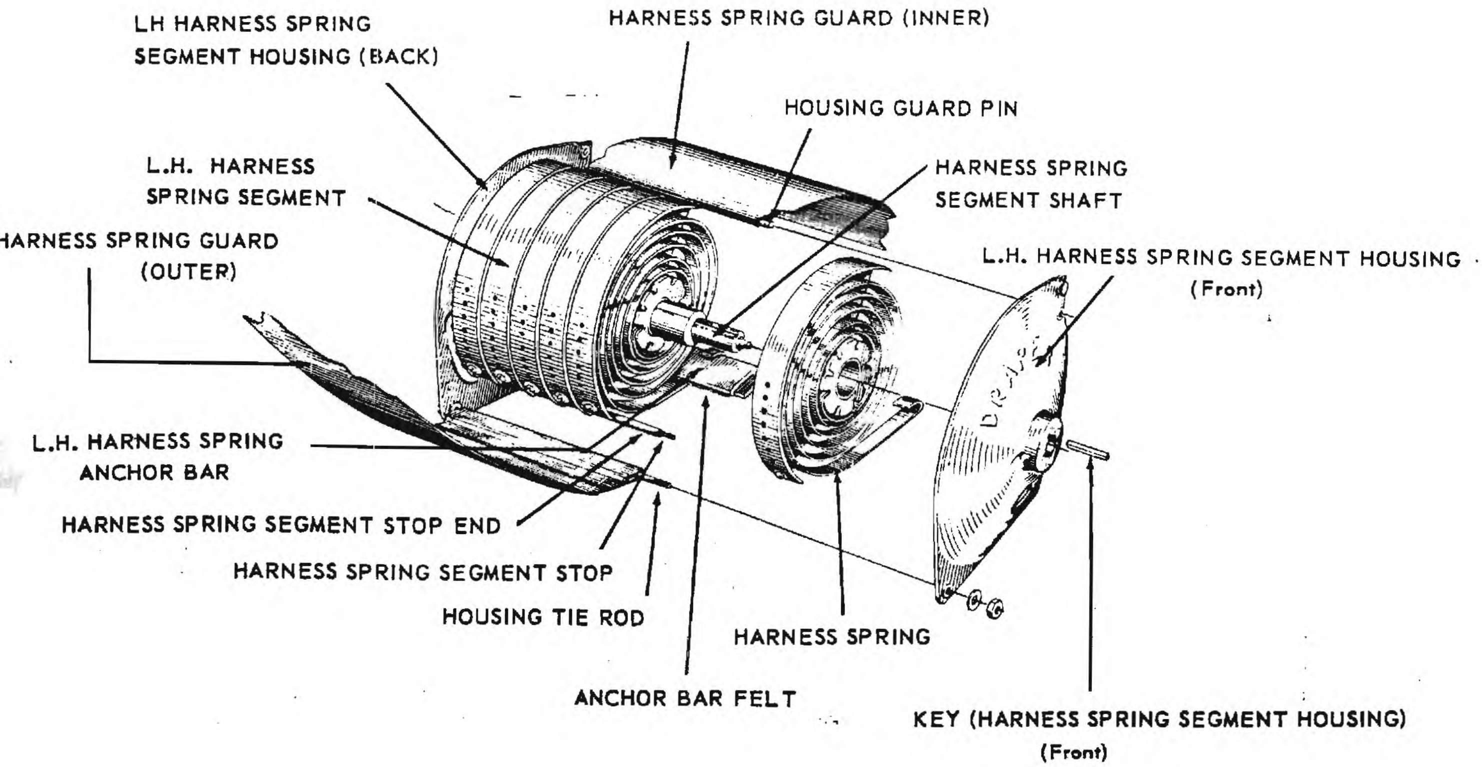


POSITIVE PULL-DOWN

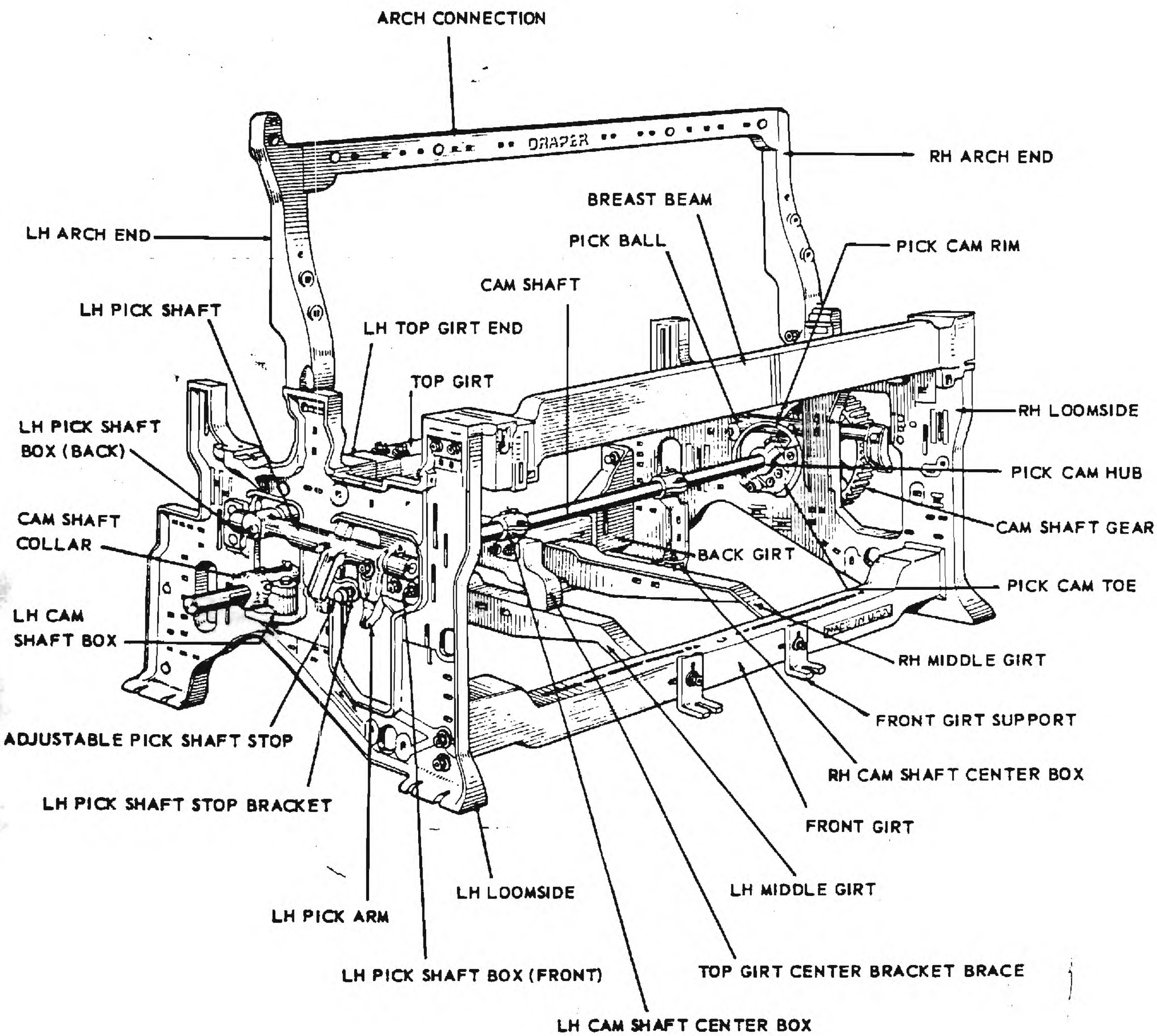
HARNESS MOTION



clock spring top

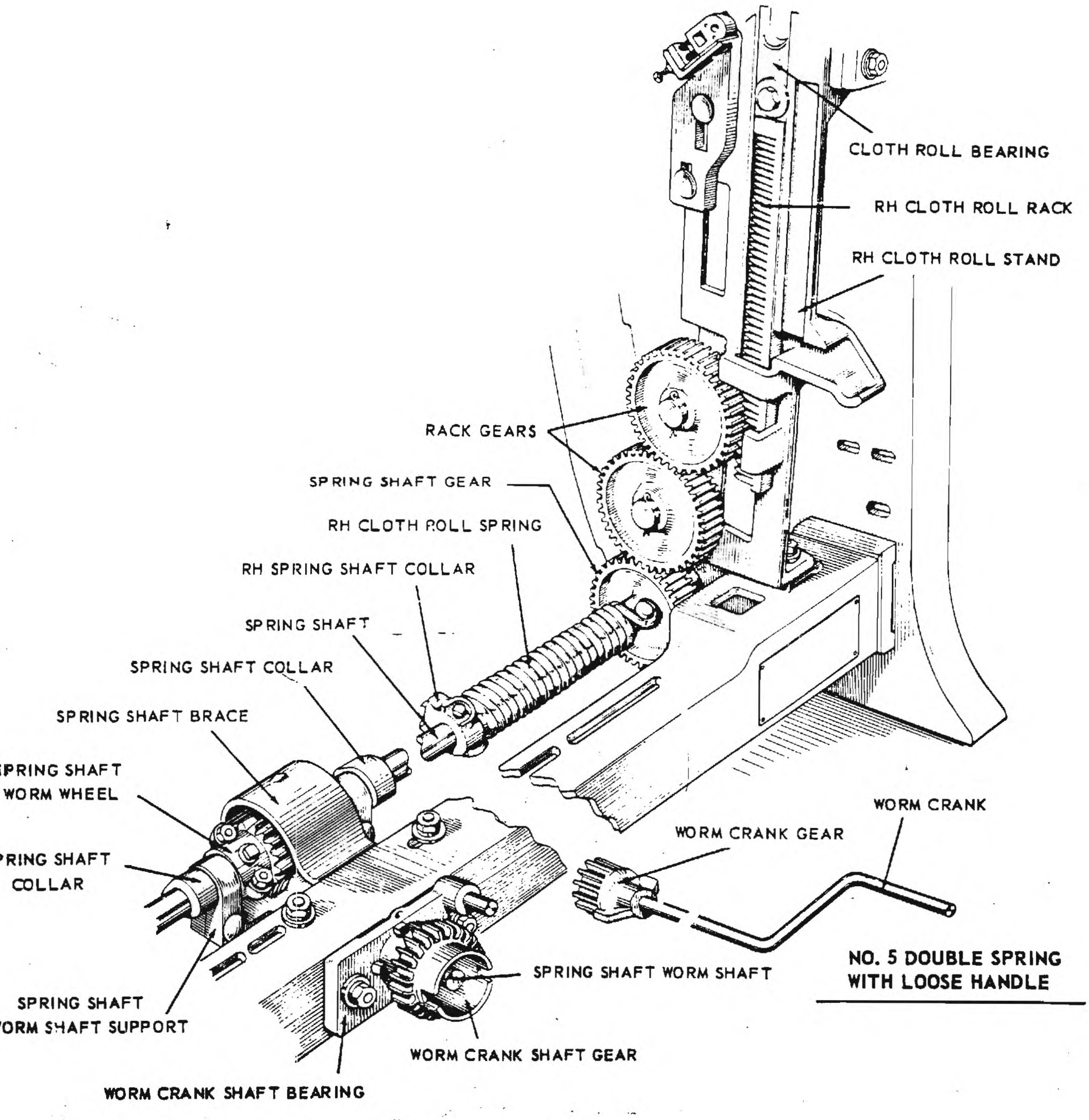


HARNESS MOTION



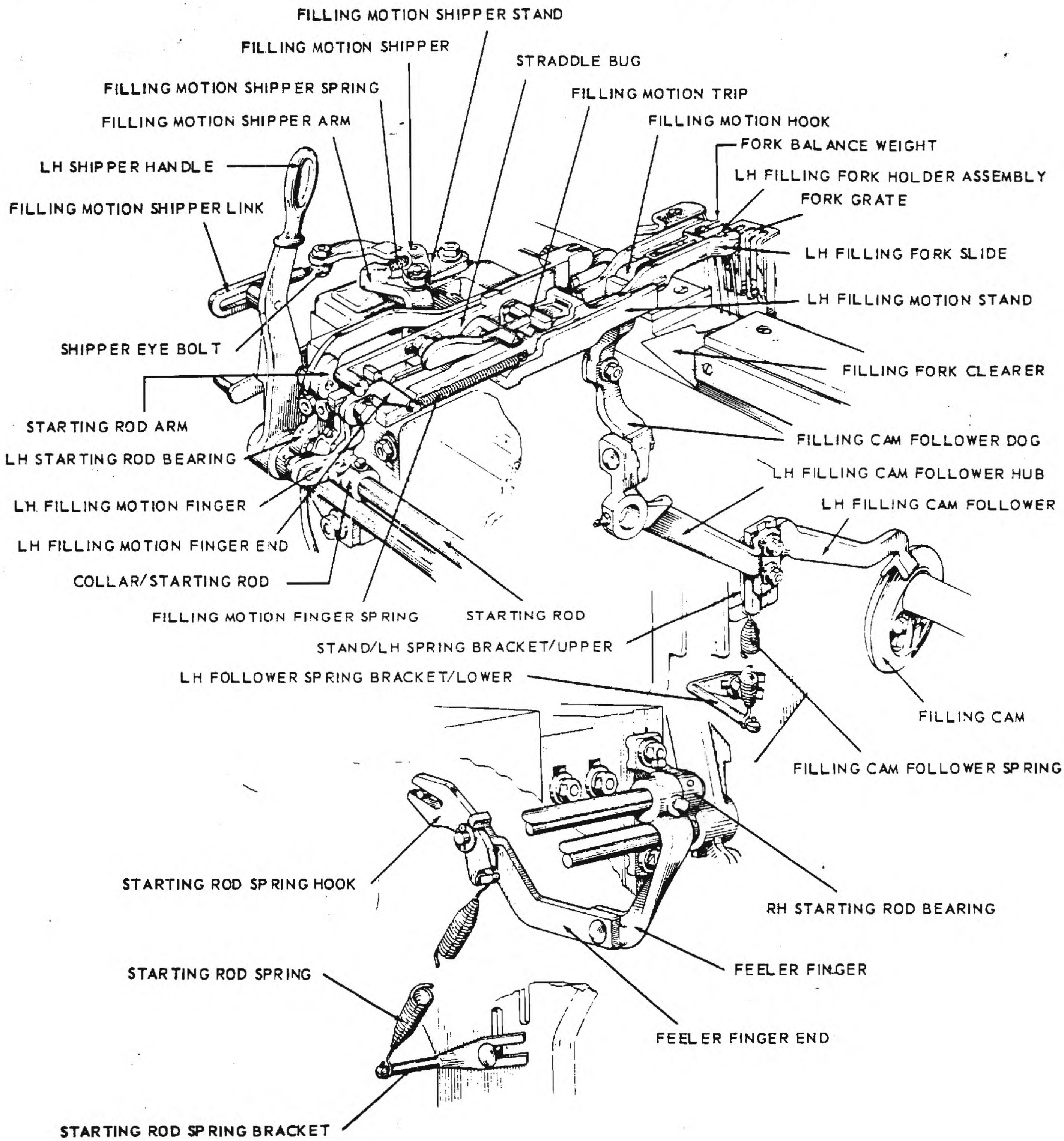
FRAME & PICK MOTION

wind-up for worm take-up

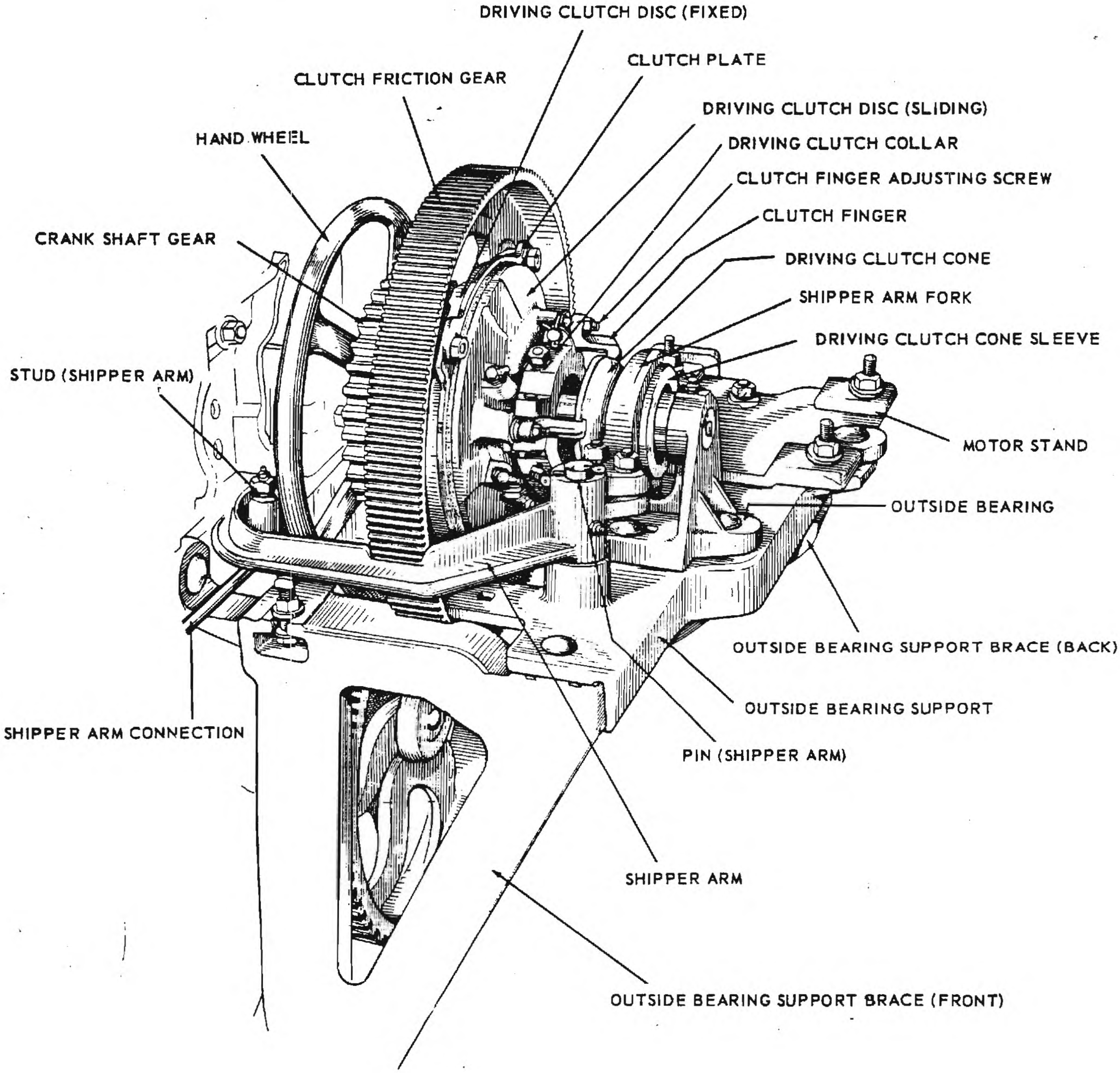


TAKE-UP MOTION

single fork



FILLING MOTION



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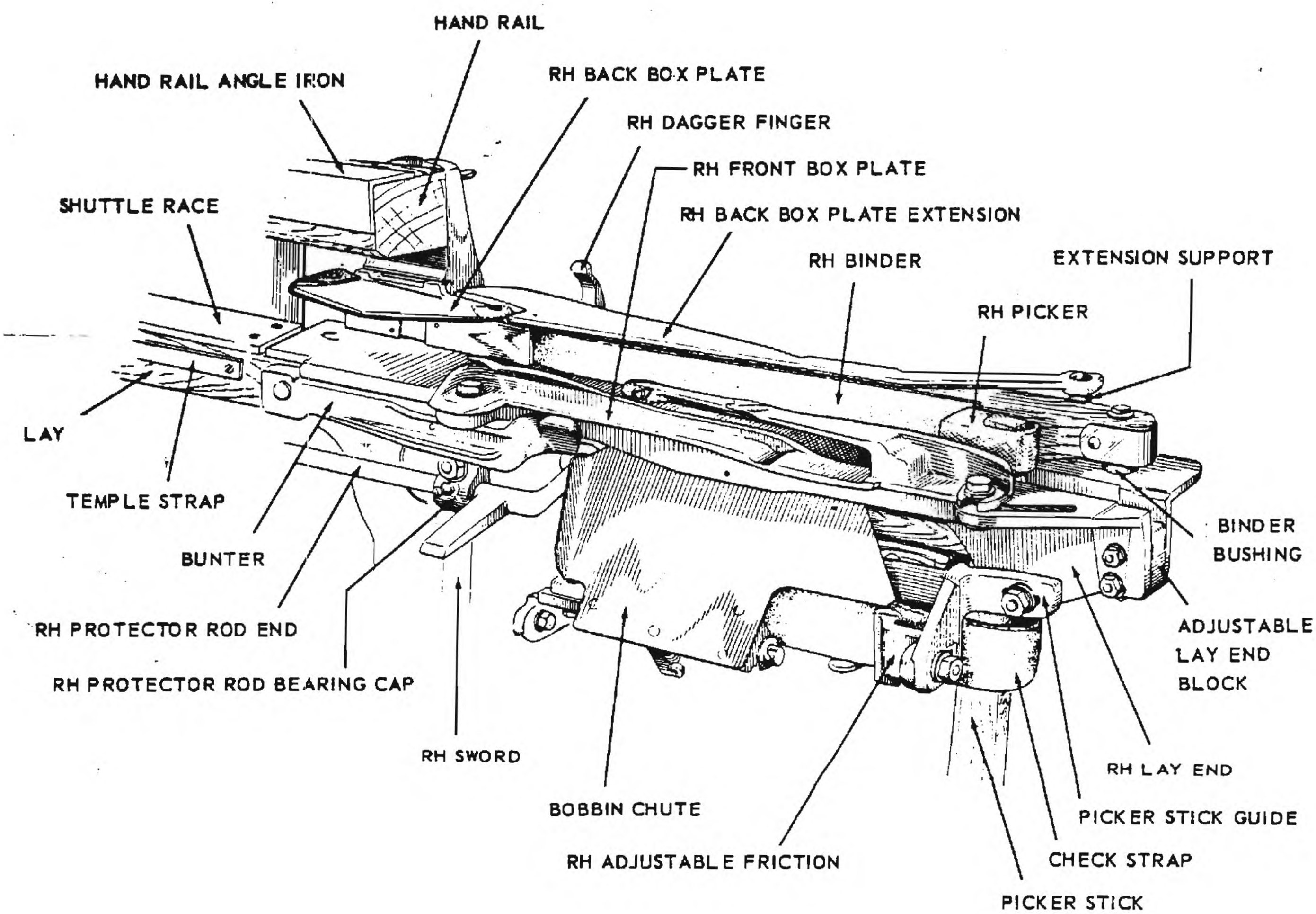
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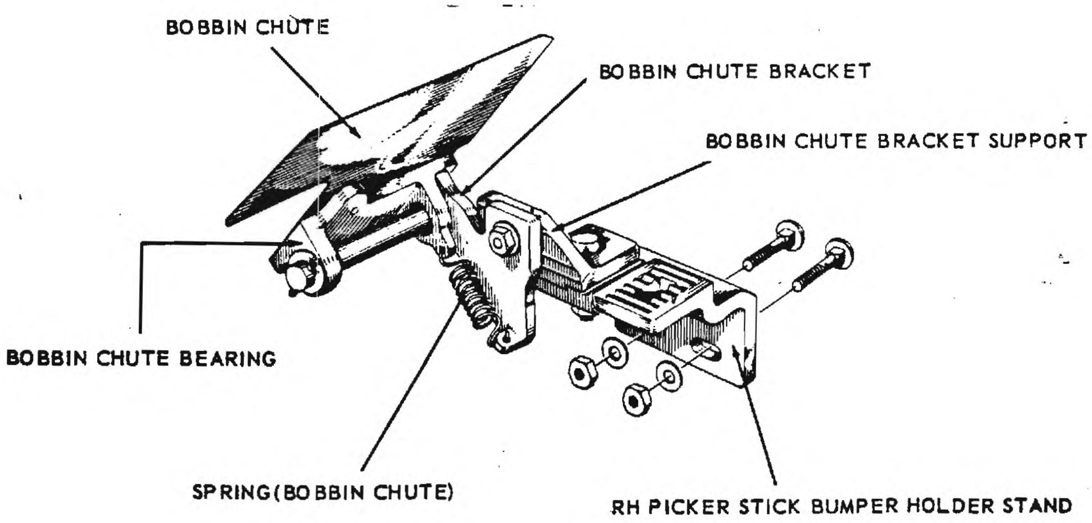
EXTENSION SUPPORT
RH PICKER
LAY
TEMPLE STRAP
BINDER BUSHING
BUNTER
ADJUSTABLE LAY END BLOCK
RH PROTECTOR ROD END
RH PROTECTOR ROD BEARING CAP
RH SWORD
RH LAY END
BOBBIN CHUTE
PICKER STICK GUIDE
RH ADJUSTABLE FRICTION
CHECK STRAP
PICKER STICK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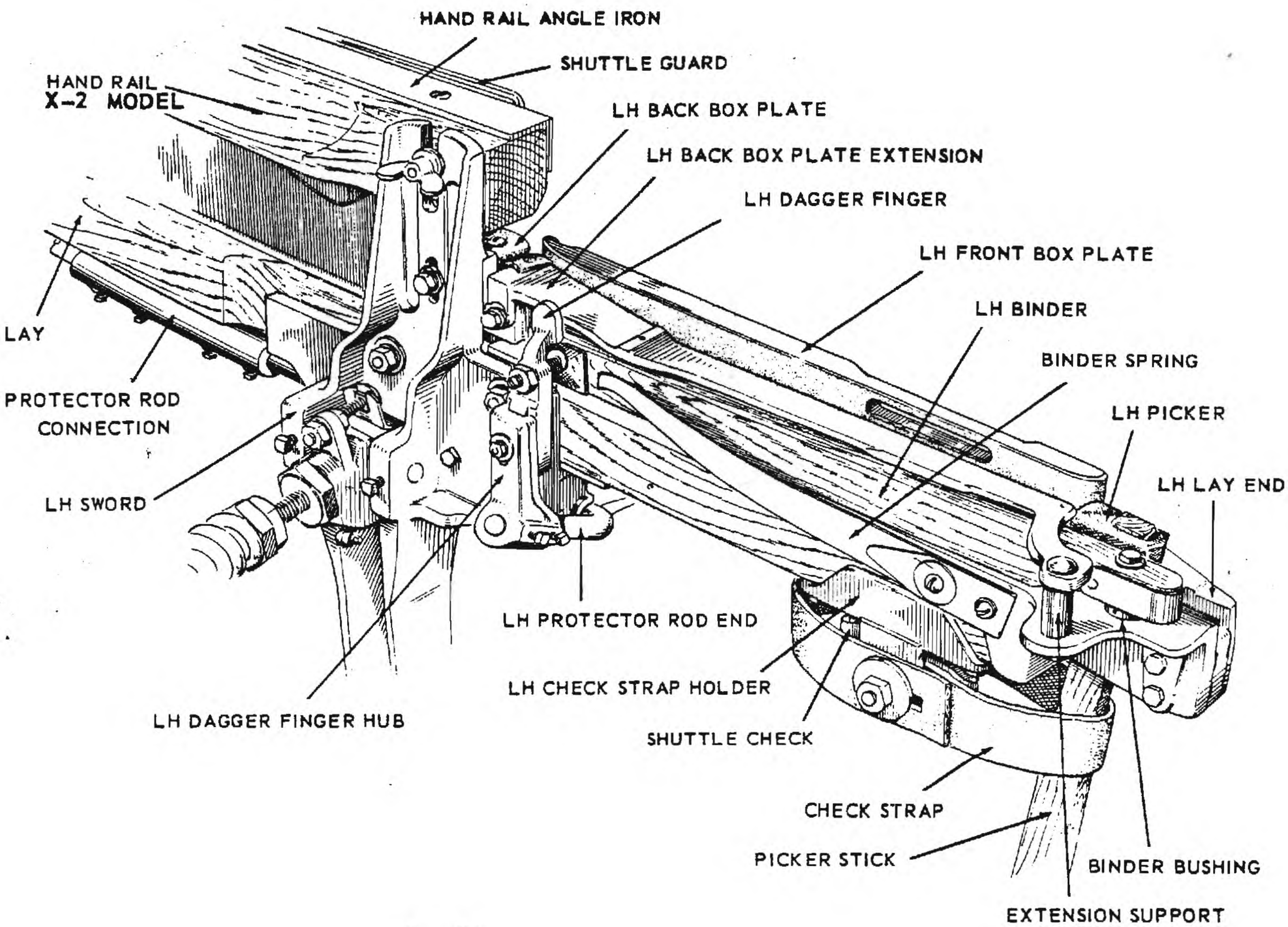
SPRING(BOBBIN CHUTE)
RH PICKER STICK BUMPER HOLDER STAND

LAY PARTS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LH BINDER
BINDER SPRING
LH PICKER
LH LAY END
LAY
PROTECTOR ROD
CONNECTION
LH SWORD
LH PROTECTOR ROD END
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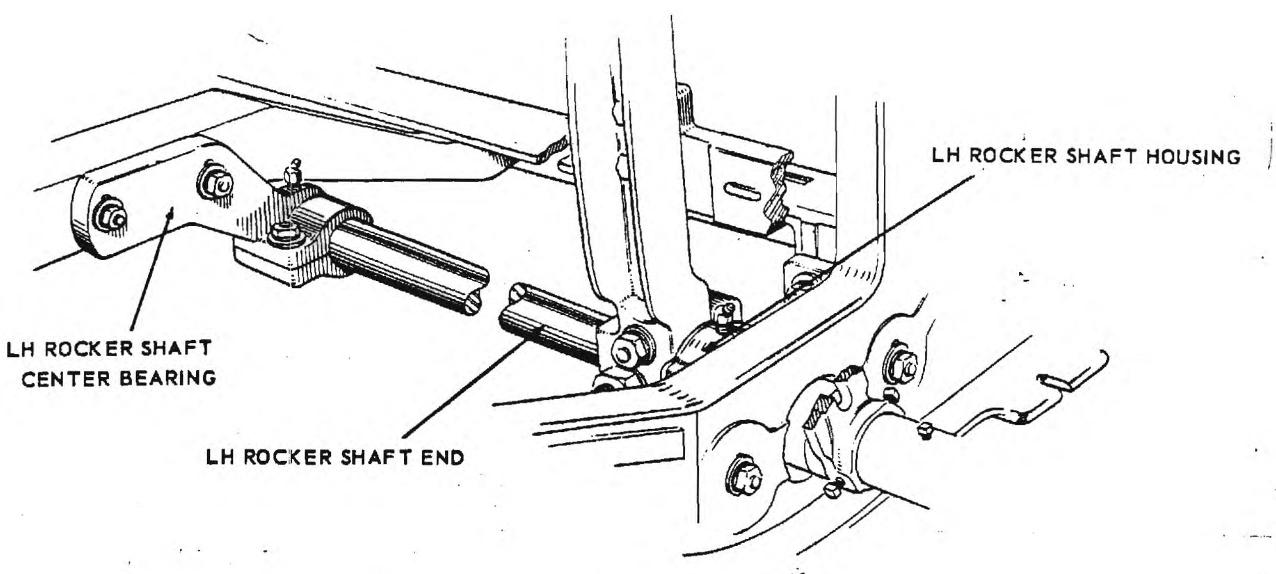
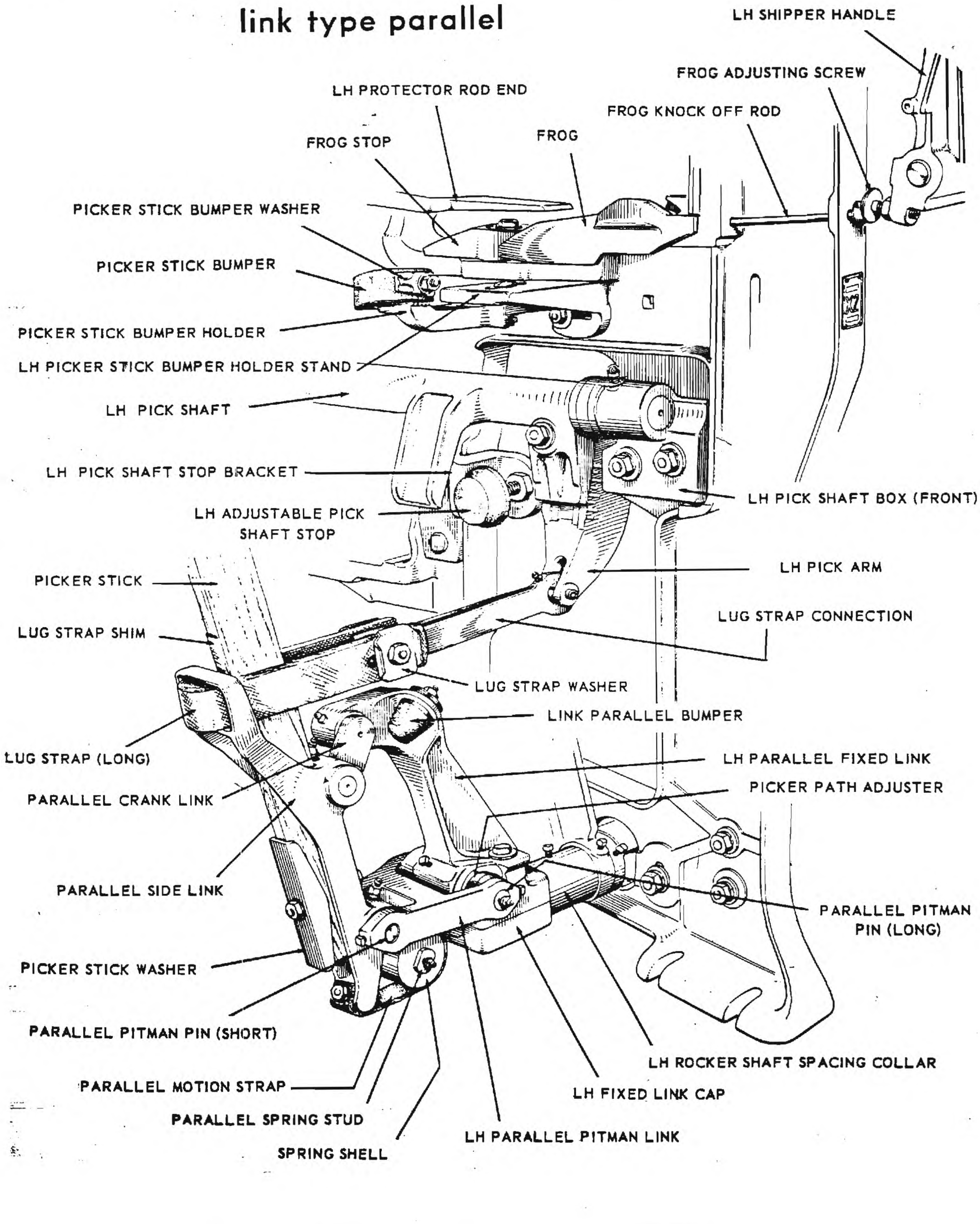
SHUTTLE CHECK
CHECK STRAP
PICKER STICK
BINDER BUSHING
EXTENSION SUPPORT

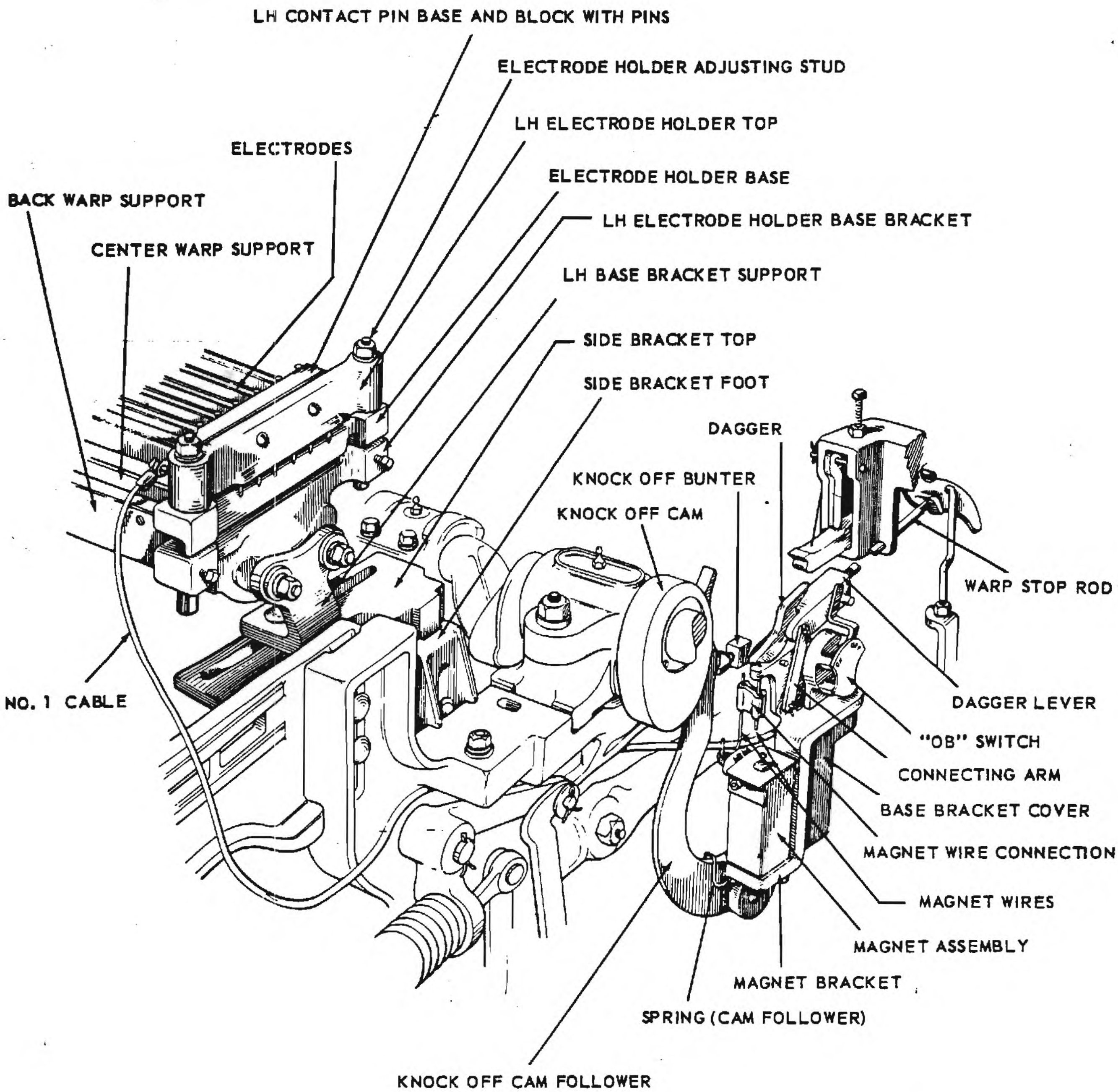

LH ROCKER SHAFT HOUSING
LH ROCKER SHAFT
CENTER BEARING
LH ROCKER SHAFT END

LAY PARTS

link type parallel



PARALLEL MOTION

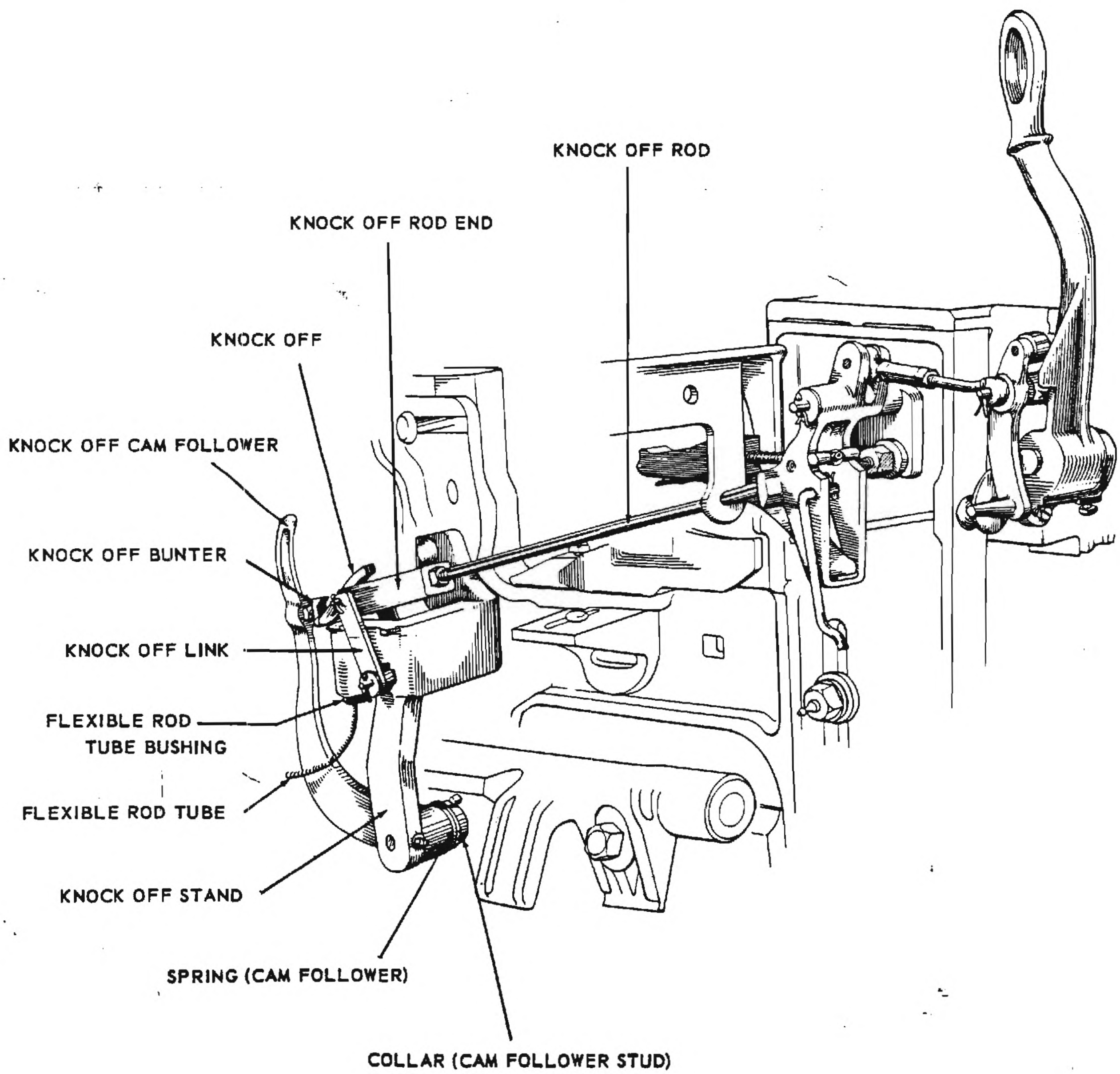


K-A electrical warp stop

#27-R knock-off

WARP STOP MOTION

#28-R knock-off



WARP STOP MOTION

APPENDIX B
Textile Materials Testing

Introduction

The three sources of textile testing standards or methods in common use in the United States are:

1.) ASTM (American Society for Testing and Materials) - Annual Book of ASTM Standards, Section 7 - Textile Materials

2.) Federal Test Method Standard No. 191 - Textile Test Methods - (approved through the GSA for all Federal Agencies)

3.) AATCC (American Association of Textile Chemists and Colorists) - Technical Manual - published yearly - Part B. Test Methods

The following discusses pertinent test methods from each resource.

ASTM Standards

The ASTM standards on textile materials are divided into two sections, namely Ø7.Ø1 on yarns and fabrics and Ø7.Ø2 on fibers and zippers. Three standards provided definition of terms. These are:

(Definitions)
D 123 - Textile Materials
D 2367 - Fabric Defects (including illustrations)
D 2368 - Classification of Man-Made and Natural Fibers

Under fibers there are three methods for tests to be performed. These are:

(Fiber Tests)
d 1774 - Elastic Properties of Fibers
D 1577 - Linear Density of Textile Fibers
D 21Ø1 - Man-Made Fibers from Filament Yarns

For yarns, three methods have been isolated. These are:

(Yarn Tests)
D 2256 - Breaking Load (Strength) and Elongation of Yarns
D 226Ø - Conversion of Yarn Number Measured in Various Systems
D 19Ø7 - Yarn Number by the Skein Method

Lastly, for fabrics, three methods applicable here are:

(Fabric Tests)
D 1175 - Abrasion Resistance of Textile Fabrics
D 1682 - Breaking Loads and Elongation of Textile Fabrics
D 2261 - Tearing Strength of Woven Fabrics.

Federal Standard No. 191

The Federal Standards follow very closely ASTM standards in many instances. Nevertheless, subtle differences have been observed and care should be taken to not assume one-for-one correspondence.

(Fiber Test)

1534 - Melting Point of Textile Fibers

(Yarn Tests)
4100 - Yarn Breaking Strength and Elongation
4021 - Yarn Number (Linear Density) of Yarn

(Fabric Tests)

5300,3302, 5304, 5306 Abrasion Resistance of Cloth

5100,5104 Breaking Strength and Elongation of Woven Cloth

5132, 5134 Tearing Strength of Cloth

AATCC Test Methods

The AATCC methods deal primarily with the reaction of textiles to organic materials, color, and chemical analyses. There are three methods of interest here.

TM 20 Fiber Identification
TM 94 Identification of Finishes
TM 93 Abrasion Resistance of Fabrics

Tests by these methods can be conducted by certified testing labs in the private sector or certified labs within the textile schools at Georgia Tech an Atlanta and North Carolina State University in Raleigh. ASTM and AATCC methods are issued annually, but the rate of change of the methods is more on the order of once per five to ten years. The Federal Standard has undergone little revision. The GSA Business Service Centers carry the standard and should carry change notices as well.

Interlaboratory test specimens may be used to compare test results if more than one testing resource is used.

E-27-615

Final Technical Report
NSG-2356

to: University Affairs Office, 241-25
NASA - Ames Research Center
Moffett Field, CA 94035
September 20, 1988

This report serves to account for the period 8-87 to 12-87 on the NASA grant NSG-2356. Final reports were completed by 8-87 and the additional time was used in preparation of a sample of molded, coated fabric based upon the old rolling convolute design for the shoulder element of the NASA space suit. All written reports on the body of the grant period were completed and submitted through normal channels. The project title was "Development of Molded, Coated Fabrics for the NASA Space Suit."

The short effort mentioned above was begun several months earlier and involved cutting a mold to dimensions taken from a drawing of the shoulder element of the space suit provided by Joe Kosmo at NASA Houston in a cooperative effort with the Houston suit development effort by Vic Vykukal of NASA Ames, the technical monitor for this grant. There was a difficult question to be answered as to whether the draw ratio of polyester fabric used in high temperature molding was sufficient to form the deep draw required by this element. As such, it was a test of the technique that had been developed. Fabric was woven to design specifications developed during the grant and a new coating material procured to allow its introduction as a safe, flexible air impermeable layer.

The fabric was molded and coated with five specimens being formed and coated. The best two of this lot were carried to Joe Kosmo at NASA Houston and a verbal report given as to its method of formation. The fabric did not achieve full fit to the form shape and thus produced an unacceptable sample with respect to the quality and conformance to shape required by the design of the shoulder element.

There has been new information this year of chemical means to assist the drawing of fabric in which a solvent saturation precedes the high temperature draw down of the fabric over a mold. Should NASA have future need of this process, it would be recommended that research be undertaken to assure the processing steps needed to achieve deeper draw down. This information was provided by Steve Hansen of DuPont in Wilmington, DE.

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